CHAPTER 2
REVIEW OF LITERATURE

The brief review of the research work related to the present investigation ‘Studies on Enhancing the Productivity and Profitability of Wheat and Mentha Intercropping under Different Methods of Crop Establishment’ was carried out under the following heads:

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2.1 EFFECT OF PLANTING METHODS

Method of planting plays an important role in the emergence and establishment of crop seedlings besides affecting soil aeration, temperature, root development and water use efficiency. Conventional flat planting is the common practice of raising crops in India. In the present decade, a new technique of crop planting namely furrow irrigation raised bed system (FIRBS) is also gaining importance in North-West India as it ensures good plant stand by improving germination (Ghildyal and Rathore, 1973) and
enhances water use efficiency (Pal, 2003). According to Kumar et al. (2004), FIRBS helps the crop to utilize solar radiation more efficiently over conventional flat planted wheat. Bed planting is a method of planting a crop on the top of raised beds with a definite number of rows. In bed planting, the land is prepared conventionally and raised beds of 37.5 cm are prepared keeping furrows at a distance of 30 cm using a specially designed raised bed planting machine termed as bed planter. Two rows of wheat are planted at 20 cm spacing on the top of the raised bed and the furrows serve as irrigation channels between the beds.

Broad Bed and Furrow (BBF) system is also an effective land management practice for maximizing infiltration, minimizing erosion and total runoff, facilitating drainage and improving water use efficiency of field crops. Concept of Furrow Irrigation Raised Bed System and Broad Bed and Furrow System alter the soil physical properties, making better aeration in the soil pores and root zone and better infiltration of water into the soil, thereby resulting in better grain yield. Permanent bed planting is another option in rice-wheat system for saving of resources. Permanent raised beds offer the additional possibility of direct seeding, reducing tillage costs and associated green house gas emissions (Ram et al., 2005). All these planting methods viz. furrow irrigation raised bed system, broad bed planting, permanent bed planting and others have been tried in wheat, soyabean, maize, groundnut and various other crops to improve resource utilization and crop yield successfully by many workers.

2.1.1 Wheat

2.1.1.1 Growth, yield and yield attributes

Bed planting may improve the resource use efficiency and increase the yield potential of wheat. There are many reports from India and Pakistan which revealed many advantages of bed planting in rice-wheat systems (Hobbs and Gupta, 2003; Connor et al., 2003). Bed planting offers many benefits like opportunity for mechanical weed control, reduced crop lodging, lowering of the seeding rates and reduced water logging (Humphreys et al., 2005). Beds also provide additional advantages like reduced germination of Phalaris minor, reduced irrigation water requirement by 30-50%, reduced water logging (Sharma and Swarup, 1988; Gill et al., 1993) and reduced seed rate
requirement by 25-30% (Dhillon et al., 2004). Owing to its positive results, it has also been recommended and included in the package of practices of Punjab Agricultural University, Ludhiana in 2002-03 (PAU, 2002).

To minimize the risk of lodging, many farmers do not irrigate the wheat crop sown with conventional flat method of planting after heading. It creates water stress at grain filling stage of wheat which adversely affects the grain yield (Hobbs, 2001). Under such circumstances, bed planting reduced the crop lodging over flat sowing and the soil applied nitrogen loses by reducing leaching and gas emissions (Sayre and Moreno, 1997). Moreover, the plants did not lodge in bed planting causing more silica content in bed sown wheat crop. Tripathi (1999) also confirmed that lodging and lodging score were reduced by 50-60 and 60-75 per cent in bed planting of wheat as compared to flat sowing, respectively. He further observed that raised beds gave significantly higher grain yield and increased the yield attributing characters.

Yadav et al. (2002b) reported higher number of grains per spike and spike density of wheat planted on raised beds than conventionally sown wheat on flat. However, potential problems with germination of wheat on beds due to rapid drying of soil surface in coarse textured soils were also observed. The lower tiller and spike density on beds were compensated by more grains per spike and higher grain weight (Singh et al., 2001; Dhillon et al., 2004; Bhardwaj et al., 2004; Sikka et al., 2004). In bed planted durum wheat, Brar and Kaler (2005) recorded higher protein content and test weight as compared to flat sowing. In another study, Kaur (2003) obtained higher grain yield of bed sown wheat and increased the water use efficiency and the crop sown on beds followed by irrigation, helped to achieve higher germination count and tiller density.

Araya (1989) on black clay soil at Mckele (Ethiopia) also observed the highest grain yield of wheat sown on raised beds with ridges at 80 cm distance in the furrows as compared to flat beds. Tripathi (1999) at Mexico reported that raised beds gave significantly higher grain yield of wheat over conventional flat sowing by increasing yield attributing characters. Contrarily, Day et al. (1978) revealed that flat plantings resulted into higher grain yields than did bed plantings; however, bed plantings produced higher grain volume weights than did flat plantings. Grain yield components (number of
heads per unit area, number of seeds per head and seed weight) were similar for both the planting methods.

Among different planting methods, Pulalov (2002) recorded wheat grain yield of 34.4, 39.6 and 36.7 q ha\(^{-1}\) under zero tillage, bed planting and conventional flat planting, respectively. Aggarwal et al. (2002) disclosed that fresh bed, conventional tillage and renovated bed system gave similar grain yield and yield attributes of wheat but significantly higher than minimum tillage system. Kaur et al. (2001a) reported that grain yield of wheat sown by bi-directional and bed planting methods was significantly higher than uni-directional (22.5 cm) and strip planting methods. Mascangni et al. (1995) remarked that growing wheat on flat raised beds (76 inches wide) or on flat conventional beds had no effect on the grain yield. Khan et al. (1987) observed that bed sown wheat produced higher grain yield of 53 q ha\(^{-1}\) compared with 40 q ha\(^{-1}\) on flat sowing due to increased N fertilizer use efficiency at Faisalabad in Pakistan. While evaluating the performance of wheat varieties (timely or late sown) under FIRBS, Kumar et al. (2004) reported that higher grain yield production was due to higher tillering capacity and its interaction with number of grains per ear. Yadav et al. (2002a) conveyed that raised bed planting saved 30-40 per cent irrigation water, increased grain yield by 20 per cent and reduced tillage cost in wheat.

Experiments conducted by Aggarwal and Goswami (2003) in different states of North-Western India showed that planting of two or three rows per bed (67.5 cm) produced grain yield of wheat similar to flat sowing. However, wheat sown on raised beds with three rows per bed out yielded two rows per bed at Delhi. According to Sekhon et al. (2004), there were no differences for 2 or 3 rows per bed, suggesting that 2 rows per bed was optimum option for wheat. Three rows per bed gave higher wheat grain yield under raised bed planting than under conventional flat planting (Chauhan et al., 1997; Hobbs et al., 1997; Khatri et al., 2001). However, Singh et al. (2002b) observed that in timely sown wheat, there were non-significant differences in the grain yield between two or three rows per bed. Nevertheless, under late sown conditions, three rows per bed resulted in significantly higher wheat yield than two rows per bed. Kaur et al. (2001c)
accounted for higher leaf area index and dry matter accumulation of wheat in bed planting (3 rows/bed) as compared to flat sowing (uni-directional 22.5 cm), though the differences were non-significant. In the same experiment, bi-directional wheat planting recorded significantly higher number of tillers m$^{-2}$ than uni-directional bed sowing (Kler et al., 1989).

At Arkansas (USA), Batchelor et al. (1980) and Sakai and Munemura (1990) revealed that on poorly drained clay soil, wheat grown on 193 cm wide beds improved the level of grain yield as compared to conventional flat planting. Shivakumar and Mishra (2001) reported significantly higher shoot number, dry matter accumulation, number of ears and ear weight at harvest but non-significant differences in the yield of wheat on broad bed and furrow method as compared to flat bed sowing. Sweeney and Sisson (1988) recorded increased yields when wheat was grown on 75 cm wide beds than flat method. Similarly, Singh (1995b) compared the ridge furrow system (1 row in the centre of furrow and 2 rows on the side of the ridges) and flat bed system of planting wheat at Hissar and obtained similar yield from flat conventional system and bed planted wheat. Smith and Smith (1988) obtained 40 q ha$^{-1}$ yields of wheat under ridge planting and 20 q ha$^{-1}$ under flat sowing.

From the findings of the scientists, it is quite evident that wheat can be grown successfully on beds in northern India, the yield being at par to higher levels than conventional sowing particularly in medium to heavy textured soils.

2.1.1.2 Nutrient uptake and profitability

Planting methods also influenced the uptake of nutrients by the plants. Kaur et al. (2001b) revealed that in bed sown wheat, availability of nutrients to crop roots increased at optimum supply of water and it might be helpful in sustaining crop yield with less seed rate, less fertilizer and less water requirement. She further, informed that higher nitrogen content was recorded in grain and straw under bed planting method (2.27% and 0.57%) than uni-directional planting (2.07% and 0.51%). Similarly, bed planting removed higher nitrogen (163.9 kg ha$^{-1}$) than uni-directional method (142.9 kg ha$^{-1}$).

Aquino (1998) and Sayre (2000) found 8-10 per cent higher yields of wheat from raised bed planting at 20-30 per cent less operational costs as compared to conventional
flat system of crop growing. Kumar et al. (2002a) observed that average net returns of bread wheat were higher under the bed planting compared to the conventional sowing. Pulalov (2002) from Uzbekistan reported 39.6, 35.7 and 34.4 q ha\(^{-1}\) of wheat yield under bed planting, conventional tillage and no tillage treatments respectively and also showed input saving in zero tillage and indicated higher output for bed planting technologies. Dhillon et al. (2002) and Singh et al. (2002b) observed that wheat was successfully grown on beds with irrigation application in furrows with higher water use efficiency. Savings were recorded in the cost of seed and irrigation application time.

### 2.1.2 Mentha

#### 2.1.2.1 Growth, herbage and oil yield

Planting methods also play vital role in the growth, development and herbage yield of mentha. Several workers tried different methods of planting of mentha under different situations.

Kaur (2001) stated that the dry matter accumulation of Japanese mint was significantly higher in flat and bed planting as compared to ridge and trench planting methods. The leaf: stem ratio and oil content were not affected significantly by different planting methods. Saini et al. (2002b) reported that flat planted mentha resulted in better herbage and oil yields over bed, trench and ridge methods of planting in loamy sand soils. He further confirmed that flat planting produced 3.9, 12.0 and 11.4 per cent higher herbage yield over bed, trench and ridge planting methods, respectively. Similarly, flat planting of mentha gave 4.8 and 10.4 per cent higher oil yield over trench and ridge planting methods, respectively.

In wheat-mentha intercropping system, mentha is planted in the end of January to first week of February. At this stage, wheat poses shading effect which is detrimental for the growth of mentha. Effect of different shade levels on herbage yield and oil content of mint have been studied by Palanikumar and Jessykutty (2007). They reported that mild shade condition (25 per cent) is ideal for mint cultivation. The highest fresh herbage yield of pepper mint (6.72 t ha\(^{-1}\)) was noticed under 25 % shade conditions at 180 days after planting while; *Mentha arvensis* produced higher oil content of 0.31 per cent at the same level of shade.
2.1.2.2 Essential oil quality and profitability

Kaur (2001) reported that the physico-chemical properties of Japanese mint viz. specific gravity, refractive index, optical rotation and free alcohols of Mentha arvensis oil were not affected considerably by flat planting, bed planting, ridge planting and trench planting. These values were within the permissible limits as prescribed by Indian Standards Institutions.

While working out the intercropping profitability, Randhawa et al. (1989) revealed that total monetary returns were increased by planting one or two rows of mentha in between two rows of sugarcane and it gave the highest returns of Rs 26,697 and Rs 25,344 ha\(^{-1}\), respectively. Gill et al. (2000) also informed that growing of Japanese mint as an intercrop in spring planted sugarcane was more remunerative than growing sole crops. Sugarcane planted in rows 90 cm apart + one row of Japanese mint gave maximum gross returns of Rs 55211 ha\(^{-1}\) and it was closely followed by sugarcane planted at 75 cm row spacing + one row of Japanese mint (Rs 54699 ha\(^{-1}\)). Experiment conducted by Singh and Sikka (2009) indicated that intercropping of two rows of mentha in sunflower grown at spacing of 90 x 20 cm and 120 x 15 cm were the two best intercropping systems because they produced significantly higher sunflower equivalent yield (41.4 and 42.9 q ha\(^{-1}\)) and net returns (Rs 31.3 and 35.6 thousand ha\(^{-1}\)) as compared to sole sunflower and other intercropping systems. In another experiment conducted by Gill et al. (2007), highest gross returns of Rs 65,520 ha\(^{-1}\) were obtained in intercropping system of Japanese mint + one row of onion.

2.1.3 Other crops

As many crops like maize, cotton, chickpeas etc. are sensitive to water logging (Wein et al., 1979; Grieve et al., 1986; Patel et al., 1987; Bishnoi and Krishnamoorthy, 1991; Dhillon et al., 1998; Thongbai et al., 2001), so raised beds offer the potential to reduce water logging stress through surface drainage and an opportunity to diversify the water logging sensitive crops under such conditions. Parfitt and Goulart (1987) reported increased seed yield of soybean (24.3 q ha\(^{-1}\)) when grown on raised beds with crests 1.6 m apart and taking 3 crop rows as compared to using the conventional method of sowing (18.3 q ha\(^{-1}\)). Jayapaul et al. (1995) reported that seed yield of soybean was in the order of beds > ridges > control (flat) and there was progressive increase in number of pods per
plant and seed yield due to broad bed and furrow land management. However, Singh et al. (1999) reported that soybeans grown on flat landforms had a higher leaf area index and more light interception compared to soybean grown on broad bed and furrow landforms. This resulted in an increase in mean seed yield for flat landform (21.2 q ha\(^{-1}\)) compared with BBF landform (18.7 q ha\(^{-1}\)).

The research activities initiated about more than 20 years ago on broad bed and furrow (120-150 cm) system in food grain crops by scientists of International Crop Research Institute for Semi Arid Tropics showed that this system works best in the areas with dependable annual rainfall averaging 750-1520 mm per year (ICRISAT, 1981). The results also revealed that raised bed and furrow system in comparison to flat bed system induced better root development, nodulation, pod filling and early maturity in groundnut (ICRISAT, 1989).

Shrivastava and Pahalwan (1972) conducted a trial on methods of planting (flat and ridge) in soyabean in clay loam soil and reported that ridge sowing increased plant height by 11.7 per cent and average seed yield by 9.8 per cent over flat sowing. Similarly, Egrochenkov and Sysoror (1968) obtained higher yield of soybean in ridge method (10 q ha\(^{-1}\)) than in flat method (6.1 q ha\(^{-1}\)). Similar type of results were reported by Egrochenkov and Sigupta (1974) who obtained average soybean seed yield of 11.9 and 7.8 q ha\(^{-1}\) for ridge and flat planting, respectively. They considered improved soil aeration, moisture, temperature and better root development to be responsible for beneficial effect of ridge and furrow method. Maximum seed yield of soybean was obtained with ridges 18-20 cm in height when height of ridges ranged between 0 and 25 cm (Sakai and Munemura, 1990). Tisdall and Hodgson (1990) observed that various crops like soybean and maize when grown on ridges gave higher yield than flat sowing due to better soil aeration. Probesh (1971) also reported that enhanced plant population and increased yields can be obtained when soybean was sown on hill tops.

Bhandari et al. (1988) compared the performance of kharif maize under three methods of planting viz. crop sown in normal rows (60 cm), paired rows (30-90 cm) and skipped rows (120 cm). They reported 4.1 t ha\(^{-1}\) grain yield under first method of planting which was significantly higher than those of second (3.6 t ha\(^{-1}\)) and third (3.3 t ha\(^{-1}\)) methods of planting which were at par to each other. At Pantnagar (Utranchal), Lal et al.
(1988) studied the effect of three methods of planting (flat, ridge and raised bed) on grain yield of maize. The highest grain yield (45.3 q ha$^{-1}$) was observed under ridge planting which was at par with raised bed (42.4 q ha$^{-1}$). Both these methods gave significantly higher grain yield over flat planting (32.9 q ha$^{-1}$).

At Hissar (Haryana), Gupta et al. (1990) observed that in black clay soils during rainy season, ridging proved not only beneficial in improving emergence of maize but also boosted the grain yield by 14-16 per cent over flat sowing by providing better soil aeration, which improved root growth for better anchorage to plants against lodging. Similarly, under poorly drained soils of North-Western Ohio (USA), ridge planting produced significantly higher grain yield by maintaining better plant population over plow planting (Eckert, 1990).

Ramakichenin et al. (2002) at Coimbatore (Tamilnadu) compared the performance of maize crop in terms of its growth and yield characters under five planting techniques viz. compartmental bunding, broad bed and furrows, ridges and furrows, flat bed sowing and flat sowing under rainfed situations in sandy clay loam and moderately well drained soils. The plants under ridges and furrows planting techniques maintained their superiority in growth characters like plant height, leaf area index and dry matter production and also kept an edge in yield attributes like cob length and number of grains per row of cob which led to significantly higher grain yield in ridges and furrow (34.6 q ha$^{-1}$) over flat planting (30.2 q ha$^{-1}$). Such a superior performance under ridge and furrow planting technique in terms of growth and yield may be due to better infiltration of rain water collected in furrows which improves the soil moisture and its availability to crop plants. As compared with flood irrigation under flat planting, the furrow irrigation under bed/ridge planting saved on an average 20-40 per cent irrigation water without reduction in crop yields of cotton (Aujla et al., 1992b) and mustard (Aujla et al., 1992a). Bed planting system increased aeration in the root zone (West and Black, 1969) and improved drainage in root zone in case of poorly drained soil (Sweeney and Sisson, 1988).

Hadvani et al. (1993) obtained significantly higher plant height, leaf area index, pod yield, pods per plant, 100 kernel weights and shelling percentage by planting on ridges under the ridge furrow method followed by broad bed and furrow and flat bed sowing. Shelka et al. (1997) recorded a non-significant difference in the pod yield of post
monsoon groundnut under different land layouts, viz. broad bed and furrow (BBF) and flat bed method at Parbhani (Maharashtra) on medium deep clay soil. Patra et al. (1999) reported that groundnut planting in broad bed and furrow and flat bed with earthing-up gave better nodulation, shoot dry weight and pod yield than planting in flat without earthing up at Mohanpur (West Bengal) on a sandy loam soil.

The literature cited above indicated that the effects of methods of planting viz. flat, ridge and furrow, raised bed and broad bed, were situation and crop specific. But, planting on beds particularly in medium to heavy soils, created more favorable conditions for the growth and development of crops by improving soil aeration, soil moisture, soil temperature, nutrient availability and reducing weed population, resulting in higher crop yields.

2.2 EFFECT OF INTERCROPPING ON GROWTH, YIELD AND PROFITABILITY

Intercropping is the simultaneous growing of two or more crops with a fixed geometric arrangement. Adoption of intercropping system is the way of increasing total production without much increase in the use of inputs. Intercropping is advantageous than sole crop because of the effective utilization of resources such as water (Olasantan, 1988; Xu et al., 2008), nutrients (Morris and Garrity, 1993; Zhang and Li, 2003) and solar energy (Harris et al., 1987; Natarajan and Willey, 1985). It gives greater stability in yield during aberrant weather conditions and epidemics of disease and pest, which is of considerable importance to subsistent farmers (Tomar et al., 1997). Other benefits of intercrops include reductions in weeds (Banik et al., 2006), nitrate nitrogen leaching (Whitmore and Schroder, 2007), soil erosion (Kirchhof and Salako, 2000), improved ground cover (Altieri, 1999), higher nutrient retention (Lithourgidis et al., 2011) and enhanced water use efficiency (Gao et al., 2009).

2.2.1 Wheat based intercropping system

There is little literature available on the intercropping of wheat with mentha. Therefore, review was conducted on intercropping with other crops also.

Kumar et al. (2002b) revealed that the co-cultivation of wheat with sucker planted mint crop gave 15% more productivity over wheat alone and 70% over mint alone. The relay cropping of wheat followed by transplanted mentha had the highest productivity,
45% higher than that of co-cultivated wheat and mint. In comparison to wheat, the sucker planted mint crop was estimated to bring in 32% higher income.

Singh et al. (2000b) stated that intercropping of wheat with potato in clay loam soil increased the land equivalent ratio as compared to sole crop of potato and wheat. He further added that maximum benefit: cost ratio was 3.64 in wheat alone followed by wheat + potato (2.68) and potato sole crop (2.47). Sharma et al. (1995) studied agronomic aspects of potato (Solanum tuberosum L.) + wheat (Triticum aestivum L. emend. Fiori & Paol.) relay cropping system. Nitrogen application to wheat not only increased the grain and straw yield, gross and net income from wheat but also the tuber yield of potato crop. Row spacing of 50 cm as well as seed rate of 80 kg ha\(^{-1}\) of wheat was found to be the optimum practice for this cropping system. Kulmi (1996) observed that production efficiency, land equivalent ratio, net returns and return per rupee invested were the highest with 4:1 wheat + sunflower intercropping. Khan et al. (2000) remarked that under the monoculture or intercropping of safflower with wheat in alternate 2, 3 or 4 row stripes, intercropping regimes gave greater economic returns than safflower monoculture.

Saraf et al. (2001) noticed that wheat + peas (1:1 row ratio) proved to be the best by giving the highest wheat equivalent yield, land equivalent ratio, net profit and benefit cost ratio among all the cropping systems. This was followed by wheat + peas (1:3 and 1:4 seed mixture). He also, informed that wheat equivalent yield was significantly higher in sole cropping of pea (38.58 q ha\(^{-1}\)) over sole wheat (32.64 q ha\(^{-1}\)). Sole pea gave the highest net profit (Rs 13964 ha\(^{-1}\)) over sole wheat (Rs 11113 ha\(^{-1}\)). Further, Subedi (1997) stated that intercropping of wheat with peas was profitable in terms of overall grain yield, land advantage, economic return and meeting the dietary requirements of all the subsistence farmers. Mallic et al. (1993) reported that the highest wheat equivalent yield was obtained with the intercropping of wheat with lentil (2.41 t ha\(^{-1}\)). Singh and Singh (2000) remarked that wheat + chick peas (4:2) recorded the highest mean wheat equivalent yield (45 q ha\(^{-1}\)). Yield advantage in terms of LER was maximum (1.13) in wheat + mustard (8:2) followed by wheat + chickpea (4:2) intercropping system.

Singh and Pal (1994) studied the association effect on wheat and mustard in respect of yield. The Sole wheat proved superior to intercropping system in respect of yield and wheat equivalent yield. Intercropping of wheat with mustard reduced the grain
yield in wheat + mustard (cv. RLM 514) by 36.7 and 25.4 percent in 6:1 and 9:1 row ratios, respectively over sole wheat. However, Mishra and Badiyala (2001) evaluated the production potential and economic viability of wheat based intercropping systems under rainfed conditions on silty clay loam soil and reported that significantly higher wheat grain equivalent yield (5629 kg ha\(^{-1}\)) and land equivalent ratio (1.57) were observed in wheat + Indian mustard (4:2). The highest net returns (Rs 36108 ha\(^{-1}\)) were also recorded in this treatment. Second best intercropping system was wheat + linseed (4:2).

Singh et al. (2000c) revealed that sowing of raya as an inter-row crop at the spacing of 2.5-3.0 m is a useful tool for increasing and assuring the per unit crop productivity. The results demonstrated the impact of extent and distribution of rainfall by testing the superiority of intercropping of raya with wheat particularly under rainfall deficient situation and seed yield varied from 3.8 to 6.3 q ha\(^{-1}\). While the impact of intercropping in year of good rainfall was availed only with wider spacing at 3 m interval and wheat equivalent yields were found comparable to the irrigated conditions and varied from 55.7 to 59.5 q ha\(^{-1}\). Singh (2003) observed that the nutrients (N, P and K) uptake by wheat and Indian mustard crops in wheat-mustard intercropping system decreased with limited water supply conditions. The higher uptake of N, P and K by grain and straw was found in sole wheat and sole mustard crops. The intercropping, in general, decreased the N uptake by grain and straw of both the crops.

Singh and Turkhede (1989) remarked that the various growth parameters, yield components and yield of wheat were more in wheat-linseed (4:1) system and least in wheat-linseed (1:1). This showed that the practice of intercropping wheat with linseed was the best from the point of efficient utilization of resources. Higher values of wheat grain equivalent and land equivalent ratio (LER) were observed in wheat + linseed (4:1) over sole wheat. The wheat grain equivalent yield increased over no nitrogen (control) by 38.7% and LER by 37.4%. The maximum net returns of Rs 2874 ha\(^{-1}\) was recorded in wheat + linseed (4:1).

Zhang and Li (2003) also observed significant yield increase of intercropped wheat over sole wheat in wheat/maize and wheat/soybean intercropping systems and positive effects of the border row and inner rows of intercropped wheat were noticed. The border row effect was due to interspecific competition for nutrients as wheat had a higher
competitive ability than either maize or soybean. Magid et al. (1991) remarked that the largest increment in grain yield was obtained when wheat was intercropped with alfalfa and supplied with nitrogen fertilizer. The beneficial effect of intercropping can probably be attributed mainly to increased photosynthetic activity during the reproductive phase of wheat growth.

### 2.2.2 Mentha based intercropping system

Singh et al. (2000d) stated that intercropping sugarcane with mint species significantly reduced canopy height of sugarcane. The reduction was higher when two rows instead of one row of mint was planted as intercrop in sugarcane irrespective of four different mint species. He concluded that sugarcane cultivar Co-LK 8001 planted at the row spacing of 90 cm could be interplanted with one row of mint under sub-tropical climate of Indian plains. This intercropping system provided sugarcane yield equivalent to that of pure crop of sugarcane and bonus yield of mint. Gill et al. (2000) reported that spring planted sugarcane with intercropping of one row of mentha yielded the highest gross returns of Rs 55211 ha$^{-1}$. Singh et al. (2002c) studied the growth behaviour, productivity and quality of four mint species (Mentha piperita, M. spicata, M. citrata and M. gracilis) intercropped with autumn planted sugarcane. The oil quality of all the four mentha species did not show significant variation due to intercropping with autumn planted sugarcane.

Sidhu et al. (2004) observed that intercropping two rows of mentha in sunflower grown at a spacing of 90 cm x 20 cm and 120 cm x 15 cm gave significantly higher sunflower equivalent yield and gross returns as compared to sole crop of sunflower or mentha. Kothari et al. (2000) investigated the productivity, economics and utilization of land, soil moisture and solar radiation under menthol mint-onion intercropping systems under sub-tropical conditions of north Indian plains. Menthol mint intercropped with one, two and three rows of onion yielded 89, 81 and 71 per cent essential oil per hectare than sole crop of menthol mint (202 kg). Likewise, the onion yield under intercropping with one, two and three rows was 46, 68 and 87 per cent per hectare than obtained from sole crop of onion (30 tonnes). The net return from intercropping of menthol mint with three rows of onion was greater by 153 percent over Rs 20450/- per hectare received from sole
crop of menthol mint. Intercropping treatments increased the land utilization efficiency by 15.4 per cent.

Gill et al. (2007) evaluated the performance of Japanese mint as an intercrop with maize, oil seed rape and onion. The fresh herb yield was highest (204.3 q ha\(^{-1}\)) in sole Japanese mint which was statistically at par with Japanese mint + one row of onion (192.4 q ha\(^{-1}\)). Oil yields were highest in Japanese mint (163.1 l ha\(^{-1}\)). Japanese mint equivalent oil yield was highest in Japanese mint + one row of onion (273 l ha\(^{-1}\)) which was on par with Japanese mint + two rows of onion (265.6 l ha\(^{-1}\)). The gross returns were also maximum in Japanese mint + one row of onion (Rs 65,520 ha\(^{-1}\)).

Singh et al. (2012) revealed that the net returns of all the menthol mint based cropping systems were 82.6-354 per cent higher than the traditional paddy-wheat-green gram cropping system. Maize-garlic-menthol mint + okra was found to be most profitable (Rs 77200 ha\(^{-1}\)) system followed by pigeon pea + sweet basil- menthol mint+ okra (Rs 76120 ha\(^{-1}\)). The benefit to Cost (B: C) ratio was highest (1.26) with pigeon pea-menthol mint, closely followed by pigeon pea + sweet basil-menthol mint + okra (1.20). The lowest B: C ratio (0.35) remained in paddy-wheat-green gram cropping sequence. This may be because of higher production cost, resulting in a comparatively lower net return.

Singh et al. (2002a) compared the chemical composition of essential oils isolated from the biomass of menthol mint cv. kalka, citronella cv. Java 2 and palmarosa cv. PRC-1 grown in the open and partial shade of five years old poplar trees. The oil of menthol mint grown in the open was richer in menthol (78.2 %). Differences in essential oil profiles of citronella and palmarosa grown in the open and partial shade were not significant.

### 2.2.3 Other intercropping system

Saini et al. (2002c) reported the reductions in sugarcane yield with intercropping of spices but because of better prices of spices in market, intercropping proved superior in net returns. Higher net returns from Isabgol intercropping in sugarcane was also observed by Sharma et al. (1997).

While conducting an experiment on cane with potato intercropping at different row spacing, Verma et al. (1986) recorded comparable cane and potatoes yield as compared to their sole crops. Cane + potato intercropping was found to be superior to
cane + mustard and cane + wheat in terms of cane yield, monetary advantage and net returns. More profitability was also observed by Kanwar (1975) in intercropping of potato with autumn planted sugarcane. However, Yadav and Prasad (1991) obtained higher cane equivalent yield in potato-sugarcane sequence than sugarcane + potato in respect of land use efficiency. Sugarcane + potato - onion was the best inter crop combination (Rahman et al., 1994; Verma and Yadav, 1988). Singh et al. (2001) explored the possibilities of growing chickpeas as an intercrop in autumn sugarcane and reported that it was economical. Sharma et al. (1993) in Madhya Pradesh reported that intercropping of chickpeas did not affect cane yield. They added that sugarcane equivalent yield was higher with intercropping compared to sole crop.

Stanford (1988) in Jamaica, West Indies, reported that short duration crops such as peas or red kidney beans could be successfully intercropped with newly planted sugarcane. In the intercropped cane, the tillers were fewer and smaller than the tillers in the pure stand of sugarcane, however, no significant effect on yield was observed between the intercropping and sole crop of sugarcane. Roodagi et al. (2001) found significantly higher cane equivalent yield in sugarcane + cowpeas system than sugarcane + maize. Wu et al. (2004) studied the effects of soyabean intercropping on the agronomic traits of eight sugarcane cultivars. Soyabean intercropping at the seeding stage had no effect on plant height, stalk diameter and brix, but it reduced only ineffective tillering significantly and number of canes, millable canes and yield of sugarcane was increased. When soyabean intercropping was conducted immediately after the planting of sugarcane, tillering and number of millable stalks were highly reduced and sugarcane output was adversely affected. Govinden and Amason (1990) determined the relative importance of competition for light and water in intercropping of maize in sugarcane in Mauritius. Intercropping maize with sugarcane caused huge reduction in the cane biomass, tiller number, cane stalk yield and sugar yield. All the adverse effects of the maize on the cane were attributed to the shading. However, Kumar et al. (2005) observed higher net returns of sugarcane with maize intercrop.

Singh et al. (2007) evaluated six intercropping systems of sugarcane with i) wheat (Triticum aestivum) (1:2), ii) raya (Brassica juncea) (1:2), iii) peas (Pisum sativum) (1:2), iv) gobhi sarson (Brassica napus) (1:1), v) barley (Hordeum vulgare) (1:2 and vi) gram
The sugarcane + gram (1:2) intercropping system produced the highest net returns (Rs.47100 ha\(^{-1}\)) followed by sugarcane + peas (1:2) (Rs.42900 ha\(^{-1}\)). The intercropping of sugarcane with barley was found to be economically unviable. They recorded the highest cane equivalent yield (91.7 t ha\(^{-1}\)) with sugarcane + gram (1:2) and it turned out to be the most profitable intercropping system with the highest net returns (Rs.47100 ha\(^{-1}\)) and the highest B: C ratio (1.06). Intercropping of legumes in sugarcane adds substantial quantity of nitrogen through mineralization, after incorporation of stalks of the intercrops. Intercropping of mungbean/cowpeas in spring planted sugarcane can bring an additional one million hectare area under pulses in northern states with their increased productivity because of high yielding irrigated environments (Ali et al., 2002).

Porwal et al. (1994) raised sugarcane after harvest of \textit{rabi} crops and compared it with growing of winter crops as an intercrop in autumn sugarcane. They reported more sugarcane yield in intercropping system than growing sugarcane after the harvest of \textit{rabi} crops except in case of potato and onion, as onion and potato vacated the field in time for timely planting of spring sugarcane. Ahmad et al. (1991) studied the feasibility of intercropping \textit{rabi} crops such as flax, \textit{Brassica juncea}, garlic, \textit{Medicago sativa} and \textit{Helianthus annuus} in autumn cane and recorded the highest net income with three rows of garlic intercropped in two rows of sugarcane.

In Punjab, intercropping of peas, radish and spinach in autumn cane proved profitable (Saini et al., 2002a). Peas intercropping did not reduce the cane yield in Madhya Pradesh as well (Sharma et al., 1993). However, in Karnataka, Patil et al. (1991) informed that intercropping of vegetables like radish and onion did not affect the yield of sugarcane but \textit{Capsicum spp.} decreased the cane yield. Intercropping of sugarcane with radish and onion provided the highest cost: benefit ratio while french bean intercropping gave highest net returns. Sharma et al. (1997) also found higher net returns from french bean intercrop. Singh and Vashist (2004) observed the economic viability of growing vegetable in autumn sugarcane. Higher net profit of Rs 4820 ha\(^{-1}\) from greengram as intercrop in pigeonpea was also confirmed by Yadav and Yadav (1981). Wali et al. (1989) remarked that niger yield was considerably reduced by intercropping and the highest yield reduction was observed by intercropping with \textit{setaria} followed by
horsegram. The highest gross returns of Rs 2612 ha\(^{-1}\) was obtained by niger + groundnut intercropping.

Li et al. (2011) studied the intercropping of faba bean/maize, wheat/maize, barley/maize and the corresponding monocultures of faba bean, wheat, barley and maize. Total land equivalent ratios were 1.22 for faba bean/maize, 1.16 for wheat/maize, and 1.13 for barley/maize intercropping over the 2-year study period. Maize was over yielding when intercropped with faba bean, but under yielding when intercropped with wheat or barley. There was an interspecific facilitation between intercropped faba bean and maize, and interspecific competition between maize and either wheat or barley. The under yielding of maize was higher when intercropped with barley than with wheat.

Hence, it is concluded that intercropping may reduce the yield of component crops as compared to sole situation, but the total yield in intercropping system results in higher productivity and profitability.

2.3 INTERACTIVE IMPACT OF INTERCROPPING AND PLANTING METHODS

Jat and Singh (2004) reported that adoption of furrow irrigated raised bed planting of wheat with 2 rows/bed and simultaneous sowing of barseem in furrows with multiple cuttings gave the highest wheat equivalent yield (7.03 t ha\(^{-1}\)) and per day productivity (57.07 kg ha\(^{-1}\) day\(^{-1}\)). This system also recorded the highest net returns (Rs 33265 ha\(^{-1}\)).

Kumar and Srivastava (1994) studied the effect of planting methods and intercropping on the yield and quality of spring planted sugarcane in Uchani, Karnal (Haryana) and reported that paired row planting proved superior over normal row and skip row methods. All the sugarcane + intercrops combinations reduced cane yield significantly in comparison to sole sugarcane. But sugarcane yield equivalent was found to be highest (96.1 t ha\(^{-1}\)) in planting of sugarcane in paired rows and intercropping with black gram in 2:3 row management. It was lowest (72.8 t ha\(^{-1}\)) in case of skip row planting of sugarcane intercropped with maize in 3:3 row management. Singh (1995a) stated that growing green gram as an intercrop with pigeonpea in normal planting at 60 cm in 2:1 row arrangement under recommended fertilization of both crops had the potential of giving maximum yields as well as monetary returns per unit area and time. Sole crop of pigeonpea produced the maximum grain yield under normal planting while
in paired row and skip row planting there was 6.8 and 21.8 per cent decline in the grain yield of pigeon pea, respectively. The reduction might be due to shading effect of plants in paired row and lesser plant population in skip row planting. Land equivalent ratio was also higher for normal planting systems compared to paired row and skip row planting systems.

Kewalanand and Anand (2008) observed that paired row planting of menthol mint on ridges + onion in furrows (2:2) and sole crop of menthol mint irrespective of planting methods caused significant increase in menthol mint yield, however, biological and economical advantages were found to be the highest due to menthol mint in furrows + onion on ridges (1:2 row ratio) giving 55 per cent more net returns compared to sole menthol mint on ridges without affecting the yield of intercrop. Land equivalent ratio (LER) was found to be significantly higher when menthol mint was planted in furrows and onion on ridges (1:2) followed by menthol mint + onion flat planting in 1:3 row ratio and menthol mint in furrows + onion on ridges in 2:2 ratio. The onion yield was found to be the highest in pure stand which was comparable to yield in 1:3 proportions of menthol mint + onion flat planting and mint in furrows + onion on ridges (2:2). Planting menthol mint on ridges + onion in furrows (1:2) or flat planting (1:1) caused 57 per cent and 56 per cent reduction in onion yield compared to sole bulb yield of onion, respectively.

Sharma and Guled (2012) remarked that intercropping system of pigeonpea + greengram under different row proportions recorded higher net income (Rs 24441 to 36916 ha⁻¹) compared to the net returns obtained from the sole crop of pigeonpea (Rs. 19474 ha⁻¹) and sole crop of green gram (Rs 9596 ha⁻¹). The pigeonpea + greengram (1:2) intercropping system under set furrow cultivation recorded the highest net return (Rs 36916 ha⁻¹) which was 23.5 per cent higher over flat bed method (Rs 29883 ha⁻¹). He further, reported that pigeonpea + greengram (1:2) intercropping system under set furrow recorded significantly higher B: C ratio of 3.11 and it was 50 per cent higher over sole pigeon pea (2.06).

2.4 EFFECT OF NITROGEN NUTRITION AND PLANTING METHODS

2.4.1 Sole crop

Nitrogen is an essential nutrient required for the normal growth and development of plants. It, being the most important growth factors affects the vegetative phase and
grain yield of crop to a large extent. However, the amount of nitrogen required by a particular genotype for giving its potential output in terms of economic yield varies with the effect of the treatments, soil type and environmental conditions.

At Faisalabad (Pakistan) Khan et al. (1987) revealed that bed planting of wheat on raised bed produced more tillers and these increased with nitrogen application. A higher grain yield of 5.3 t ha\(^{-1}\) was observed in bed sown wheat as compared to 4 t ha\(^{-1}\) with flat planting which was because of increased nitrogen fertilizer efficiency in the bed system. Mascangni and Sabbe (1990) reported increase in N uptake with increase in N levels up to 150 kg N ha\(^{-1}\) in bed planted wheat.

Brar and Kler (2005) observed similar grain yield of bed planted wheat with nitrogen dose of 120 and 150 kg ha\(^{-1}\) indicating the possibility of reducing the nitrogen dose for bed sown wheat. Singh et al. (2001) also found that application of nitrogen at 120 and 180 kg ha\(^{-1}\) produced similar grain yield of bed planted wheat. Mascangni et al. (1989) found variation in grain yield response of wheat to increasing N rates in crown beds, flat raised beds and flat conventional. Sayre and Moreno (1997) at CIMMYT, Mexico reported an increase in grain yield with each increment in N levels upto 300 kg N ha\(^{-1}\) to bed planted wheat. In the experiments conducted at Ludhiana, the grain yield continued to increase in bed planted wheat with each increment of N and 180 kg N ha\(^{-1}\) recorded the highest grain yield (PAU, 1997). Singh (1998) remarked that N application at 50 percent higher rate over the recommended level (120 kg N ha\(^{-1}\)) in flat and bed planted durum wheat increased the grain and straw yield by 4.6 and 7.6 per cent, respectively. Also higher level of N (180 kg N ha\(^{-1}\)) increased the number of spikelets per spike by 1.1 percent and 1000 grain weight by 1.3 percent over recommended level. In another experiment with flat and bed system, grain yield of wheat increased by 60 per cent with increase in N from 75 to 150 kg ha\(^{-1}\). Tripathi (1999) reported that under conventional flat planting and conventionally tilled bed planting, the N rates of 180, 240 and 360 kg N ha\(^{-1}\) were statistically at par in their yield response and 360 kg N ha\(^{-1}\) produced the highest yield, whereas in permanent beds, 240 kg and 360 kg N ha\(^{-1}\) resulted in significantly higher grain yield of wheat over 180 kg N ha\(^{-1}\) while 240 and 360 kg N ha\(^{-1}\) were statistically at par among themselves. Kaur (2000) observed that yield contributing characters of wheat like spikelets per spike and grains per spike increased
with 150 and 210 kg N ha\(^{-1}\) over 120 kg N ha\(^{-1}\) under different planting techniques, however, 1000 grain weight decreased significantly. Application of 150 kg N ha\(^{-1}\) produced higher grain yield of wheat by 2.1, 2.6 and 8.6 percent over 120, 180 and 210 kg N ha\(^{-1}\).

On the basis of experiments conducted at different locations under furrow irrigated reduced-till bed planted system (FIRBS), Chauhan et al. (1999) concluded that 150 kg N ha\(^{-1}\) was optimum for higher production in Northern Hill and North Western Plains Zone whereas 120 kg N ha\(^{-1}\) was found to be the optimum dose for North Eastern and Central Zones. Sweeney and Sisson (1988) reported that ridge method resulted in higher yields of wheat than either reduced or conventional tillage. Yields tended to be greater with dribble than broadcast applications of urea ammonium nitrate solution as a spring top-dress, especially for Arkan variety of wheat.

Dhillon et al. (2004) conducted studies on the effect of different planting methods in relation to nitrogen on growth and yield attributes of wheat. The ears m\(^{-2}\) were significantly higher in flat planted wheat as compared to bed. There were non significant differences in grains per ear and test weight under different tillage/planting methods. The grain yield was significantly higher in flat planted wheat as compared to bed planted wheat. The effect of nitrogen was significant only in grains per ear whereas test weight differed non-significantly at all nitrogen levels. The grain yield increased significantly with increase in nitrogen level from 120 to 180 kg ha\(^{-1}\). Tuteja et al. (2005) remarked that the higher application of nitrogen (30-40 %) reduced the growth and yield of mint compared to application of 10 and 30 % nitrogen. This could be owing to the reason that emergence of suckers and initiation of roots in Japanese mint needed at least 25 to 30 days, thus application of basal nitrogen was not efficiently utilized by the crop as most of the nitrogen applied was lost either through leaching or volatilization.

### 2.4.2 Intercropping system

Verma et al. (1997) found that intercropping of wheat + Indian mustard (8:1 row ratio) with 100 per cent recommended fertilizer to both the crops (NPK 80, 16 and 16 kg ha\(^{-1}\) to wheat and NP 60 and 12 kg ha\(^{-1}\) to Indian mustard) gave a bonus yield of Indian mustard (2.79 q ha\(^{-1}\)) without any significant reduction in wheat yield (32.48 q ha\(^{-1}\)) and
also produced the maximum wheat equivalent yield (37.26 q ha\(^{-1}\)). The highest crowding coefficient (7.97), land equivalent ratio (1.19), maximum net returns of Rs.8334 ha\(^{-1}\) and benefit cost: ratio of 1.46 indicated better compatibility and yield advantage of this intercropping system.

Tomar et al. (1996) studied the response of wheat based legume intercropping systems to nitrogen under limited moisture availability conditions. Higher values of growth and yield attributes (shoot m\(^{-1}\), leaf area index, effective shoots, grains spike\(^{-1}\), grain weight m\(^{2}\)) of wheat were recorded in intercropping with legumes than those of sole crops. The highest values were observed for wheat and gram or chickpea (Cicer arietinum L.) in 2:2 ratio. Wheat responded to N favourably up to 90 kg ha\(^{-1}\) in terms of yield and yield attributes (effective shoots m\(^{-1}\) and grain yield m\(^{-1}\)). In legumes, sole crops recorded higher growth and yield attributes and grain yield. Legumes showed marked response up to 30 kg N ha\(^{-1}\) only. Highest total productivity in terms of wheat equivalent yield was observed in sole chickpea (40.3 q ha\(^{-1}\)) and sole lentil (43.4 q ha\(^{-1}\)) during respective years. Among the intercropping systems, wheat and chickpea in 2:2 ratios recorded the highest equivalent yield and land equivalent ratio.

Dhakad et al. (2004) reported that land equivalent ratio was highest (1.39) under wheat + chickpea 4:2 row ratio than wheat + chickpea 2:2 row ratio (1.29) and wheat + chickpea 2:1 row ratio (1.29) receiving 80 kg N ha\(^{-1}\) in all planting systems. Similarly, higher wheat equivalent yield was obtained under wheat + chickpea 4:2 row ratio. Singh and Sarawgi (1995) observed that grain yield of wheat was significantly higher in 2:1 crop row ratio than 2:2 ratio and mixture treatment. The effect of N scheduling was also remarkable and showed that by saving 25% N to wheat crop, yield of either crop was not much affected.

Singh et al. (1996) conducted study on wheat-gram intercropping systems under rainfed situation in North-Western India with four levels of spatial arrangement (in row replacement series) and four levels of N. Wheat and gram yields were the highest in their respective sole crop situation. However, yield of intercrop wheat out yielded than its expected sole wheat yield at the same sown proportion. But in wheat + gram intercrop situation, companion gram yields were lower than that expected sole gram yield at the same sown proportion. Wheat crop both in sole as well as in intercrop system responded
to N application up to 50 kg N ha\(^{-1}\). N uptake by wheat grain was more in intercrop wheat as compared to expected N uptake by sole wheat at the same proportion.

Sharma et al. (1995) revealed that nitrogen application to wheat not only increased the grain and straw yields and gross and net income from wheat but also the tuber yield of potato crop. Tomar et al. (1997) studied the dry matter accumulation and nitrogen uptake patterns in wheat based intercropping systems as affected by N fertilizer. Sole crop of wheat, lentil and chickpea produced higher dry matter than intercropping systems. Sole lentil recorded highest nitrogen uptake over other cropping systems closely followed by sole chickpea. Application of 90 kg N ha\(^{-1}\) recorded 46.3, 13.1 and 6.2 % higher N uptake than 0, 30 and 60 kg N ha\(^{-1}\), respectively.

Singh et al. (2000a) found that intercropping of legumes led to N economy in winter maize which responded linearly to nitrogen application up to 200 kg N ha\(^{-1}\) when grown as sole crop. The optimum nitrogen doses for maize + pea and maize + lentil were 150.8 and 147.0 kg N ha\(^{-1}\), respectively. They also revealed that intercropping of two rows of peas between two rows of winter maize fertilized with 150 kg N ha\(^{-1}\) gave the highest gross and net returns and proved more remunerative than sole maize and wheat. Net returns per hectare were Rs 26,454, 14,611, 14,168 and 18,107 from maize + pea, maize + lentil, sole maize and wheat, respectively. They also found the highest maize equivalent yield (125.0 q ha\(^{-1}\)) and land equivalent ratio (1.94) at the same level of nitrogen.

Singh (1995a) assessed the economic feasibility of intercropping pigeon pea with green gram under varying levels of fertility and planting systems. He studied that normal planting of pigeon pea with green gram in 2:1 ratio as intercrop system with recommended fertilizers for both the crops (i.e. 30 kg N + 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) for pigeon pea and 20 kg N + 40 Kg P\(_2\)O\(_5\) ha\(^{-1}\) for green gram) produced the maximum gross returns (Rs 6749 ha\(^{-1}\)) followed by 50 per cent (Rs 6213 ha\(^{-1}\)) and 25 per cent fertilization to intercrop green gram under normal planting pattern of pigeon pea (Rs 5976 ha\(^{-1}\)). Land equivalent ratio also established the advantages of intercropping systems.
In general, it was observed that wheat responded to N application significantly from 120 to 180 kg N ha\(^{-1}\) in flat and bed planting under sole and in intercropping system. The interactive impact of N with various row ratios and land configurations needs to be further investigated for optimizing N application and to enhance the productivity and profitability of wheat based intercropping systems.