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BRASSICA BASED INTERCROPPING SYSTEMS- A REVIEW

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ABSTRACT

The traditional practice of mixed cropping has gained popularity in recent years in the form of intercropping with a suitable modification in planting pattern. Intercropping is defined as growing of two or more dissimilar crops simultaneously on the same piece of land, in a distinct row arrangement using one crop as a base crop to which rows of an additional component crop is added. The recommended optimum plant population of the base crop is suitably combined with appropriate additional plant density of the component crop. Intercropping provides significant advantages in land use efficiency, crop productivity and monetary returns as a result of effective use of solar energy and inputs as compared with sole cropping under diverse agroecologial situations. Selection of crop and agronomic requirement aspect are very important. In principle component crops should have contrasting maturities to reduce competition for the same resources at the same time, variable rooting pattern for better utilization of moisture and nutrients from different soil depths, different plant height/type for efficient use of light. Moreover, the intercrops should have either synergistic or complementary effect relative to the base crop. Intercropping of mustard, an important *rabi* oilseed crop of Northern India, with cereals and pulses is a traditional practice to realise yield stability as well as to fulfil the needs of oil and grains. In view of change in global scenario of demand and supply and also prices of oilseeds and food grains, *Brassica* based intercropping assumed great significance to generate more income per unit area under specific set of conditions. If recommended row ratio of mustard with cereals like wheat, barley and pulses like chickpea, pea, lentil for a specific area is adopted then farmers could utilize applied and available resources more efficiently and effectively on sustainable basis. These row ratio combinations with variation in, growth and development of both the component crops are also being deviated, which ultimately affects the yield attributes and yield, but at specific combination land equivalent ratio and yield advantage is definitely augmented. The suitable and appropriate row ratios combination varies from place to place due to change in climate, farming practices and varieties of crops cultivation. The research avenue is adequate with mustard + cereals and pulses intercropping in relation to management of irrigation, fertilizer, genotypes and crop geometry. Intercropped oilseeds and pulses crop may have the potential for a more efficient use of resources compared to sole crop. Intercrops are considered as less susceptible to pests and diseases and may inhibit weeds more efficiently resulting in enhanced yields and profitability.

Key words: Oilseed *Brassica*, Rapeseed-Mustard, Intercropping, Yield, Economics.

India has achieved great strides in production of food grains, the low level of production of oilseeds is a matter of great concern. The increasing gap between demand and supply of vegetable oils in the country can be bridged only by increasing their production per unit area per unit time due to non-availability of land for further expansion of area under oilseeds. In India, over 65 per cent of the total vegetable oil produced is derived from soybean and rapeseed-mustard. Rapeseed-mustard stands second in edible oil production after soybean in India and most important oilseed in winter season with an area of 5.82 m ha and production of 5.83 m tonnes during 2007-08 (Anonymous, 2008). There is very little chance for horizontal growth of the crop. Thus, production of rapeseed-mustard can be increased by vertical growth of the crop through intercropping with other crops. Nowadays, rapeseed-mustard called as oilseed *Brassicas,* has been found successfully intercropped mainly with different crops *viz.* chickpea, lentil, sugarcane, potato, wheat, etc. under various agroclimatic zones of the country.

Intercropping can be broadly defined as a system where two or more crop species are grown in the same field at the same time during a growing season (Ofori and Stern, 1987). Intercropping is a crop management system involving the growing of two or more economic dissimilar crop species or varieties in distinct row combinations simultaneously on the same piece of land (Ahlawat and Sharma, 2002). Conceptually, intercropping system helps for risk avoidance from epidemic of insect-pest and disease, and overcome the effect of adverse environmental conditions in agro-climatologically unstable regions along with better utilization of solar radiation and inputs like fertilizer and water compared to crops in sole system. It means intercropping not only reduces the risk factors, but also increases the profit (Rathi and Verma, 1979). Another form of intercropping involves cover crops, where understory crops are used not for an economic yield but for other benefits such as weed suppression (Liebman, 1986). Intercrops suppress weeds by reducing the available space for weeds (Liebman, 1986 and Unamma *et al.,* 1986). Sengupta *et al.* (1985) opined that greater cover provided by the intercropping reduce weed growth by competition. Enhanced competition from intercropping can be exhibited through soil shading and resource competition that impedes weed germination and growth (Anil *et al.,* 1998). Intercropping generally reduces yields of component crops from what they would be in monoculture, but intercrops have the potential to more effectively use the land area i.e. higher land equivalent ratio (Anil *et al.,* 1998). There are further more strong rationales behind preponderance of this practice like catering to the multiple needs of the farmer, a self provisioning device, a mechanism to spread labour peaks, keeping weeds under check etc (Singh and Jha, 1984a). Moreover, intercropping does not increase greatly the water requirement, but improves the water use efficiency under both rainfed and irrigated conditions (Mandal and Mahapatra, 1990). This is possible through increase in availability of water to the plants, increased conversion efficiency or increase in harvest index. Nevertheless, it is necessary to re-evaluate and recombine various activities at higher input levels (Palaniappan and Sivaraman, 1996). When two or more crops are raised in intercropping system, one comes across two situations, firstly, the intercrops grows better in the presence of another and exceeds in yield advantage over sole crop (Willey, 1975). Secondly, the adverse effect of competition between component crops is noted and yield advantage compared to sole crop is lowered (Ahlgren and Alamode, 1939). Through the competition effect between principal and subsidiary crops depend on the maturity periods, rooting pattern, canopy spread and plant habit etc. of the component crops (Singh and Gupta, 1994). The yield advantage obtained through intercropping has been reported due to efficient utilization and optimization of available natural growth resources *viz.* water, light as well as air and space (Singh and Gupta, 1994). Besides, it sometimes produces allelopathic effect (Rice, 1974). Similarly, Willey (1979a, b) made critical analysis of the advantage accrued from the system. As early as in 1949, Aiyer highlighted the advantages and beneficial effects of growing crops of dissimilar nature as mixed/intercropping in India. Recently, Mandal *et al.* (1991a, b) again established the fact that intercropping system gave yield advantage over monoculture due to temporal complementarity. Bora (1999) has also considered intercropping as potentially beneficial system of crop production and provides greater stability of yield advantage compared to sole cropping in a given set of environment and under particular planting pattern owing to varying competitive behaviour of two crops when grown in association. Therefore, suitable modification of planting pattern and a careful selection of crops in intercropping can reduce the mutual competition to a considerable extent (Verma *et al.*, 1997 and Yadava *et al.*, 2002).

Different *Brassica* based intercropping systems are discussed as under:

1. Effect on growth

1.1. Oilseed *Brassica* + Wheat Intercropping

Intercropping association of wheat and mustard are predominantly grown in Indo-Gangetic plain areas of sub-tropical climate both under irrigated and rainfed conditions of India. The intercropping system of mustard (*Brassica juncea* L.) and wheat (*Triticum aestivum* L.) has been recognized as a potential system for augmenting the productivity and profitability per unit area and time in subsistence farming or assured input supply system. It also provides employment to farm families as well as biological insurance (Singh and Jain, 1984 and Singh and Jha, 1984b). This system is a promising one with respect to economical viability (Saran and Giri, 1985 and Malik *et al.*, 1985) and yield advantage (Sharma *et al.*, 1986) under optimum set of conditions and is also known for land augmenting device (Jodha, 1979). With the introduction of high yielding varieties of wheat in India, the practice of wheat and mustard intercropping has been on decline, but it needs re-evaluation in light of changing price structure and demand of wheat and Indian mustard (Singh *et al.*, 1991). To achieve higher yield advantage, a proper row ratio is necessary to maintain in intercropping of wheat and mustard because aerial competitive behaviour of these two crops in association varies at different sowing proportion (Bora, 1999). This differential behaviour of the two component crops with respect to inter row competition may be due to their varying canopy height and spread. Average wheat canopy is lower than the mustard, and spread of mustard plants is greater than wheat. Thus, in intercropping, mustard has the advantage as it is more exposed to the sun and wheat suffers more as it grows under the mustard canopy (Singh *et al.*, 1995).

Advantage of mixing two crop species is likely to occur when individual components are of different morphological and growth frame (De and Singh, 1981). Nevertheless, the higher yield advantage and productivity could only be achieved under optimum proportion of each component in the intercropping system when plants of both the species faced relatively less competition for growth resource use (Kushwaha, 1992a). Since mustard grows faster than wheat, it competes better for growth resources (Kumar and Ahlawat, 1986).

Mandal *et al.* (1986b) observed that the leaf area index (LAI) and dry matter (DM) accumulation in sole wheat was significantly higher than of wheat + mustard in 4:2 row proportion at 75, 90 and 103 days after sowing. Besides, Mandal *et al.* (1985) confirmed that treatments involving wheat, mustard and chickpea grown alone, or wheat in combination with mustard and chickpea affected branching and plant height in mustard and chickpea. However, during winter seasons on a sandy clay loam soil at Pantnagar, Uttarakhand in 1981-83, mustard + wheat intercropping in 2:4 and 2:10 row ratio though remained comparable but produced significantly higher mustard branches plant^{-1} than 1:1 row ratio (Sharma *et al.*, 1986). Saxena and Das (1990) studied the growth and other attributes of mustard and wheat grown either in pure stands or intercropped in 1:2 row ratio under limited water supply conditions and reported in intercropping system, growth in terms of LAI and DM production decreased in wheat but not much affected in mustard compared with their respective pure stands. Though according to Mandal *et al.* (1991b), the maximum DM was recorded in mustard + wheat intercropping at 90 days after sowing, grown in 2:4 row combination. Singh *et al.* (1991) observed that marked reduction in tillers per unit area of wheat in 1:1 row ratio as compared to 2:10 row ratio of mustard + wheat intercropping. In another study, wheat dry weight plant^{-1} was reduced in intercropping of mustard + wheat in 1:9 row combination as compared to wheat pure, whereas plant height remained unaffected (Pandey, 1995). However, Singh *et al.* (1995) working on mustard + wheat intercropping with various row ratios *viz.* 1:3, 1:6, 1:9, 2:3, 2:6 and 2:9, recorded minimum number of branch plant^{-1} of mustard at 1:3 row ratio and maximum at 2:9 row combination and difference among various row ratios did not prove significant. Srivastava and Verma (2007) at Varanasi, Uttar Pradesh observed that association of mustard with wheat under 1:8 row ratio recorded the maximum values of LAI and dry matter accumulation of both the crops but the magnitudes of these parameters decreased markedly in 1:5 and the minimum was with 1:2 row ratio, whereas, harvest index of wheat decreased significantly from 1:8 to 1:2 row ratios. Therefore, based on the available literature on intercropping of mustard with wheat or other related winter crops, it may be concluded unanimously that the growth and development parameters of the component crops in association deviated from their respective solid stands. This could be probably due to reduced seed rate and inter space competition between them for light, space and nutrients growing in the vicinity to each other.

1.2. Oilseed *Brassica* + Chickpea Intercropping

Chickpea and mustard is a prominent intercropping system not only in the Indo-Gangetic plains of north India but in the entire Indian sub-continent on dryland conserved moisture conditions. Scientific approach of intercropping of these two crops increases the productivity per unit area per unit time under a situation where two crops are grown in intercropping at a certain proportion and row ratio (Ali, 1988). To increase the production per unit area, mustard + chickpea intercropping provide resources to the resource poor farmers, more efficient use of land and labour, and better control of weeds, insects/pests, and pathogens than sole crops (Singh and Rathi, 2003). Intercropping of chickpea with mustard was more beneficial than intercropping of wheat with mustard (Prakash, 1992). Mandal *et al.* (1994) reported that chickpea + yellow *sarson* intercropping significantly reduced the dry matter production than their component crops. Arya and Jain (2003) observed the highest number of branches, dry matter accumulation and dry weight of root nodules of chickpea with mustard var. Vardan + *kabuli* chickpea var. BG 1003 intercropping. Increase in growth attributes in different Indian mustard genotypes might be due to the least competition of chickpea. Kumar and Singh (2006) reported that plant height were significantly higher when Indian mustard was grown in intercropping than as sole crop.

1.3. Oilseed *Brassica* + Lentil Intercropping

Intercropping of mustard with lentil was more profitable than sole crops at Kanpur, Uttar Pradesh (Kushwaha, 1992b); Sangrur, Karnataka (Hedge, 1993) and Bahraich, Uttar Pradesh (Singh and Rajput, 1996). The mustard and lentil intercropping system recorded significantly superior values of LAI and crop growth rate (CGR) than that of the sole mustard cropping system (Patra *et al.,* 1994). Singh *et al.* (2000) reported that sole lentil cropping system recorded significantly superior values of dry matter accumulation and CGR than that in mustard and lentil intercropping system and the higher values for yield attributes were recorded with sole mustard but the differences with the mustard and lentil intercropping system were non-significant. This might be due to the better utilization of the sunlight under sole planting whereas under the intercropping system, lentil was shaded by the tall mustard. Singh and Rana (2006) reported that Indian mustard + lentil intercropping recorded significantly superior values of LAI and dry matter accumulation than sole Indian mustard stand. Further, Singh *et al.* (2009) observed plant height of brown *sarson* remain unaffected due to intercropping with lentil. Moreover, spatial arrangement and plant population in an intercropping have important effects on the balance of competition between components crops and their productivity.

1.4. Oilseed *Brassica* + Cash Crops Intercropping

The success of mustard intercropped with sugarcane can be ascribed to better complementary use of growth resources in both space and time. Wider row spacing and slow initial growth of sugarcane offers little competition to mustard. Mishra *et al.* (1989) observed that dissemination of smut (*Ustilago scitaminea* Mundkar) spores was interrupted when mustard was intercropped between healthy and diseased rows of sugarcane due to reduced air turbulence. However, growing of intercrops in between cane rows causes shade to the base of sugarcane plants from where tillers emerge. Tiller production is hampered and hence dry matter accumulation is greatly reduced. Therefore, short duration varieties of companion crops which vacate the field much earlier than the tillering phase of sugarcane caused little adverse effect of sugarcane.

Singh *et al.* (1985) found the relay intercropping of rapeseed (one cut for fodder at 60 DAS) + potato followed by berseem was more remunerative than pure crop of potato. Narwal and Prakash (1989) at Hisar, Haryana reported that intercropping of *gobhi sarson* (*Brassica napus*) with potato was more beneficial than with mustard (*Brassica juncea*). Yadav (1984) and Rathi *et al.* (1992) suggested inclusion of mustard variety Varuna than any other variety of mustard for its intercropping with potato. Likewise for potato, short duration variety Chandramukhi gave the best performance (Rathi and Verma, 1979).

Intercropping system can be practiced to get more agronomic advantages. Simmonds *et al.* (1992) reported that *Allium spp*. are very effective antifeedant and Kirtikar and Basu (1975) reported that *Allium spp*. have strong pungent repelling action. Singh and Kothari (1997) compared aphid infestation on mustard (Rohini) monocrop with intercrop treatments of artemisia (*Artemisia annua* L.), coriander (*Coriandrum sativum* L.), chamomile (*Matricaria chamomilla* L.), fennel (*Foeniculum vulgare* Mill.) and dill (*Anethum sowa* Kurz.) and found that fennel intercropped resulted in significantly lower aphid population in mustard.

2. Effect on yield attributes and yield

2.1 Oilseed *Brassica* + Wheat

In major wheat growing areas of India, farmers by and large sow mustard (*Brassica spp.*) as an intercrop under irrigated conditions. Keeping this fact in view, a multi-location trial was planned and implemented with the set objectives to investigate whether the intercropping of mustard has any adverse effect on the wheat yield and consequently, the results from Agra (Uttar Pradesh), Pantnagar (Uttarakhand) and Kanpur (Uttar Pradesh), indicated a small decline in wheat yield in the intercropping. However, this was compensated well with the yield of high priced mustard under 1:8 mustard and wheat row ratio (DWR, 1987). Similarly, Malik *et al.* (1998) from Rawalpindi, Pakistan also reported that the losses in wheat yield under intercropping system were compensated by increased income from the intercrop. Kumar and Thakur (2006) observed decrease in yield with replacement series and increase with additive series which can be ascribed to direct effect of the population of main crop of wheat towards yield and advantage to *Brassica* crops like brown *sarson* and mustard, in replacement series of intercropping and however, seed yield of *Brassica* crops decreased significantly in mixed cropping. Decrease in wheat grain yield in intercropping with rapeseed and mustard has been reported by other workers too

(Dwivedi and Namdeo, 1992 and Singh and Yadav, 1990). Mandal *et al.* (1985) in an experiment involving mustard and wheat grown alone or in mustard combination with wheat noticed that the number of siliqua in mustard was the highest when grown alone and number of grains siliqua^{-1} markedly reduced in combination with wheat. An experiment was conducted by Sharma *et al.* (1986) during winter season on a sandy clay loam soil of Pantnagar, Uttarakhand, observed that the adverse effect of mustard on wheat was enhanced with its increasing population and 1000-seeds weight and siliquae plant^{-1} of mustard remained unaffected in intercropping. Additionally, Pandey (1995) reported from Kanpur, Uttar Pradesh found that weight of wheat grain spike^{-1} was reduced in intercropping of mustard + wheat in 1:9 row ratio with respect to wheat pure. Similarly, Singh *et al.* (1995) reported that the number of shoot or spike bearing tiller of wheat m^{-1} row length was the highest under pure stand and it decreased significantly when the wheat was grown in any combination with Indian mustard. Increasing proportion of Indian mustard from 1:8 to 1:2 row ratio of mustard + wheat intercropping, markedly reduced grains spike^{-1}, effective tillers m^{-1} and 1000-grain weight of wheat, whereas siliquae plant^{-1} were the highest under 1:8 row combination and reduced significantly with an increase in mustard population (Srivastava and Bohra, 2006). However, it is not surprising that some benefit from intercropping can be claimed under one range of plant populations (Osiru and Willey, 1972). Therefore, total and component population as well as spatial arrangement relationship is the major components of agronomic study that are necessary to maximize the yield in intercropping (Willey, 1979b). It was observed that in various wheat and mustard intercropping treatments, the adverse effect of mustard increased with its increasing population and the lowest wheat yield was recorded at highest mustard population and vice-versa (Srivastava and Bohra, 2006 and Srivastava *et al.*, 2007). Similarly, Batra *et al.* (1987) also suggested that wheat yields were affected most adversely when mustard was alternated after every two rows of wheat over 4:1 and 6:1 row ratio of wheat + mustard. Nevertheless, Sawhney *et al.* (1983) reported that intercropping of mustard + wheat (1:8) gave additional yield of Indian mustard without impairing the wheat yield. Similarly, Saini *et al.* (1989) also stated that sowing one row of mustard alternated with eight or nine rows of wheat gave an additional mustard seed yield of 2-3 q ha^{-1} without affecting wheat yield. Intercropping of wheat and mustard at the row ratio of 6 or 10 rows of wheat alternated with 2 rows of mustard was being found practically most feasible in conditions of R.S. Pura in Jammu (Gupta and Singh, 1989). However, Yadava (2002) while summarizing the results of multilocational trials concluded that one row of mustard after every ninth row of wheat proved appropriate method of mustard + wheat intercropping in Rajasthan, Eastern Uttar Pradesh and Punjab. Mustard and wheat in 2:10 row proportion recorded optimum under irrigated conditions of Pantnagar (Uttarakhand), Navsari (Gujarat), Rohtak (Haryana), Sirsa (Haryana) and Jind (Haryana), though mustard + wheat in alternate rows was found better at Kalyani, (West Bengal) Saxena and Das (1990) stated that wheat grain yield markedly decreased while that of mustard seed yield increased in 1:2 row ratio of mustard and wheat intercropping compared with their pure stands under limited water supply conditions. However, Mandal *et al.* (1991b) obtained 588 kg ha^{-1} of mustard seed yield in mustard + wheat intercropping with 2:4 row ratio as compared to 1556 kg ha^{-1} in its sole stand. On the other hand, Nayital and Sharma (1991) reported 29% increase in total productivity due to *gobhi sarson* (*Brassica napus*) + wheat intercropping in 1:4 row ratio as compared to sole wheat. During 1978-79 to 1985-86, examination of the relative effect of growing wheat with mustard under All India Coordinated Agronomic Research Project revealed that different mixed ratios, led to yield loss for wheat mostly in the range of 30-40 per cent. However, the crops grown under intercropping systems with 1:2 and 1:3 row ratios showed relatively less yield loss in wheat crop (Choudhary and Bhatia, 1992). It means intercropping of mustard and wheat under specific row ratio had favourable conditions for higher yield advantage as compared to their mixed systems. The recommended and optimum row ratio may be varying from place to place, but Dwivedi and Namdeo (1992) suggested that mustard + wheat in 1:2 row ratio could be used at Kuthulia, Rewa (M.P.) as rainfed. However, Puri and Suri (1994) at Akrot, Palampur (H.P.) observed that 2:4 row ratio of mustard and wheat as compared to 1:4 exerted relatively higher depression in growth and development of wheat due to increased competition for plant nutrients, moisture and solar radiation between component crops. At Pantnagar, (Uttarakhand), it has been found that the maximum reduction in wheat grain yield (63.34%) occurred in 1:1 row ratio, whereas it was 25.28% in 2:10 mustard + wheat row ratio (Singh and Gupta, 1994). In various row intercropping systems, the highest yield of wheat was recorded at 1:3 row ratio at Kharwad, Karnataka (Hiremath *et al.*, 1993), 2:8 mustard + wheat ratio at Niphad, Maharashtra (Patil *et al.*, 1995) and 1:8 row ratio at Varanasi, Uttar Pradesh (Srivastava and Bohra, 2006 and Srivastava *et al*, 2007), though mustard performed better at 2:2, 4:4 and 1:2 row ratio for Kharwad, Niphad and Varanasi, respectively. In Jamalpur (Bangladesh), Rahman (1999) reported maximum wheat grain yield in 1:3 row ratio of rapeseed + wheat and intercrop produced the highest seed yield in 1:1 row ratio on alluvial soil under rainfed conditions. Grain yield of wheat was recorded significantly higher in its pure/sole stand but it reduced drastically due to mixing and/or intercropping with mustard (Srivastava and Bohra, 2006 and Srivastava *et al.*, 2007) and the lowest wheat yield was recorded at the highest mustard population. However according to Singh *et al.* (1991), the reduction in grain yield of wheat was 12.36 per cent in 2:10 and 36 per cent in 1:1 row ratios of mustard + wheat in 1986-87 and 20 and 48 per cent, respectively in 1987-88. Bora (1999) also reported similar results for yield of grain and straw both with rapeseed. Similarly, the yield of Indian mustard was the highest in its pure stand and it declined significantly with decrease in its population in wheat and mustard mixed and/or intercropping systems (Singh *et al.*, 1995; Dwivedi *et al.*, 1998; Srivastava and Bohra, 2006 and Srivastava *et al.*, 2007). However, according to Singh *et al.* (1991), on unit area basis, seed yield of mustard was higher in intercropping than in pure cropping. Greater canopy of Indian mustard, which in turn intercepts greater part of light, enhances its incident solar energy utilization efficiency, thereby putting wheat to a disadvantage. The effect of inter row competition in Indian mustard was just reverse to that observed with wheat (Singh and Gupta, 1994 and Singh *et al.*, 1995). Singh *et al.* (1995) studied mustard + wheat row combinations of 1:3, 2:3, 1:6, 2:6, 1:9 and 2:9 along with control (mixed cropping) and they obtained the lowest yield of wheat in 2:3 combination due to its lowest number of rows per unit area *vis-à-vis* highest intra specific competition. However, wheat grain yield under 1:9 row ratio was the highest *i.e.* 2.74 t ha^{-1} but it gave only 0.29 t ha^{-1} of mustard seed yield.

2.2 Oilseed *Brassica* + Chickpea

Bohra *et al.* (1999) studied the intercropping system of mustard and chickpea in different ratios and found all the intercropping treatments recorded yield advantage over sole cropping of mustard and chickpea. Jana *et al.* (1995) intercropped mustard with chickpea and lentil and found that all intercropping treatments of mustard + chickpea were better in relative crowding coefficient, land equivalent ratio, monetary advantage, relative net return, area time equivalent ratio and relative value total, giving greater productivity per unit land than monocultures. Singh and Rathi (2003) got higher productivity for intercropping of mustard and chickpea in the 1:4 row ratio than for sowing of mustard and chickpea in sole stands in terms of land equivalent ratio Reduction in yield attributes and seed yield of chickpea was minimum in wider (1:8 or 1:9) compared with narrow row ratios of mustard + chickpea (Patel *et al.*, 1991 and Singh and Yadav, 1992). Better yields in wider spatial pattern of intercropping system were also reported by Waghamare *et al.* (1982). Significantly more number of pods per plant, grains per pod and grain weight per plant of chickpea were recorded with 2:2 row ratio compared with 1:2 and 1:3 row ratio, whereas seed yield of chickpea was greater in 1:3 row ratio of mustard + chickpea intercropping. However, yield of sole crop of chickpea was the maximum (Sachan and Uttam, 1992). Patel *et al.* (1991) obtained maximum seed yield of mustard with sole crop which decreased significantly with increase in chickpea row in intercropping system. Studies have, however, revealed that reduction in mustard yield was not proportional to decrease in its plant population in the intercropping system (Singh *et al.*, 1988). Reduction in seed yield of mustard was the lowest in 1:4 spatial arrangements in a wet year and in 1:6 row ratio of mustard + chickpea in dry year (Saran and Giri, 1985). Sachan and Uttam (1992) reported maximum mustard yield in 2:2 (6.3 q ha^{-1}) followed by 1:2 (5.2 q ha^{-1}) and 3:1 (3.5 q ha^{-1}) row ratios, respectively in mustard + lentil planting pattern. Vyas and Rai (1993) reported that mustard + chickpea in 3:1 planting pattern resulted in higher yield of mustard (27.2 q ha^{-1}) compared to 4:4 row ratio (21.1 q ha^{-1}). At Jobner, Rajasthan, Keshwa *et al.* (1988) observed that the highest seed yield of mustard was registered in 1:2 mustard + chickpea intercropping. The productivity of mustard + chickpea (1:4 or 1:3) intercropping system was higher than that from either of the component crops grown separately at Kanpur, Uttar Pradesh (Rathi, 1980). Singh (1981) observed that intercropping of Indian rape (*Brassica tornifortti*) with chickpea increased total yield by 41-70 per cent compared to sole crop of chickpea, whereas Singh *et al.* (1987) corroborated that paired planting of mustard (30/90 cm) + 2 rows of chickpea gave 19.1 q ha^{-1} of mustard with additional 10.6 q ha^{-1} of chickpea. Samsuzzaman *et al.* (1995) evaluated the performance of mustard and chickpea (*Cicer arietinum*) intercropping at different levels and got best results considering yield and economic returns from mustard 75% + chickpea 25% among other combinations. Ahlawat *et al.* (2005) and Tripathi *et al.* (2005) recorded reduction in yield of Indian mustard due to intercropping with chickpea. Abraham *et al.* (2010) reported that intercropping of chickpea and mustard in 4:1 row ratio was significantly superior to sole crops of either mustard or chickpea in terms of yield.

2.3 Oilseed *Brassica* + Lentil

Singh *et al.* (2000) noticed that maximum reduction in yield attributes was recorded in brown *sarson* intercropped with lentil in 1:1 row proportion due to greater shading and competition effect of the intercrops on lentil. Intercropping significantly reduced the grain and straw yields of lentil compared with those of sole lentil due to more interspecific competition. Tiwari *et al.* (1992) also reported similar reduction in Indian mustard yield by intercropping with lentil due to the depressing effect of the later on the former crop. Singh *et al.* (1999) observed that higher lentil grain equivalent yield under mustard + lentil intercropping systems might be due to efficient utilization of resources and less competition between the component crop species. Among different varieties of mustard, mustard variety Kranti proved the best when intercropped with lentil (Singh and Rajput, 1996). However, seed and straw yields of intercrop of mustard and lentil decreased as compared with their sole crops and reduction in seed and straw yields of mustard under the intercropping system was 6.2 and 4.0%, respectively, which was not significant than that of the sole cropping system of mustard leading to non-significant difference in growth parameters and yield attributes values of mustard. Therefore, it showed that the better compatibility of mustard with lentil in the intercropping system (Premi *et al.,* 2002). Tiwari *et al.* (1992) observed that seed and straw yields of the lentil intercrop decreased under the mustard and lentil intercropping system owing to less plant population per unit area and more shading effect of tall growth habit of mustard leading to lower values of growth and yield attributes such as dry matter accumulation, crop growth rate, pods per plants, seed weight per plant, seeds per pod and 1000-seed weight and caused 74.4 and 64.3% reduction in seed and straw yield of the lentil intercrop over the sole lentil, respectively. Organic mulching affects the plant growth and yield mainly through conservation of soil moisture in addition to regulation of soil temperature and its effect on physical and chemical properties of soil (Mandal and Mahapatra, 1993). Increases in seed and straw yield with increased fertility levels in mustard + lentil intercropping have been reported by Kushwaha (1992b) and Katiyar *et al.* (2003) in mustard. Singh and Rana (2006) reported reduction in lentil seed yield when intercropped with Indian mustard. In brown *sarson*, Singh *et al.* (2009) recorded that siliqua length, number of seed siliqua^{-1} and 1000-seed weight remained unaffected due to various intercrop row ratios with lentil, but significantly higher number of siliquae plant^{-1} was in all row ratios of brown *sarson* + lentil intercropping compared to sole crop. However, yield of brown *sarson* decreased due to reduced number of plants in intercropping.

2.4 Oilseed *Brassica* + Cash Crops

Autumn planting of sugarcane is prevalent in Northern India due to favourable climatic conditions for germination and growth. Loss of *rabi* crop due to autumn planting of sugarcane can be compensated through intercropping in sugarcane (Narwal and Malik, 1981). These intercrops provide protection to sugarcane from frost. Kumar (1983) and Shivay *et al.* (1996) suggested inclusion of Varuna variety of mustard in mustard + sugarcane intercropping system. Kanwar *et al.* (1988) reported significant reduction in tiller number and cane yield in mustard + sugarcane intercropping system as compared to cane alone. Singh *et al.* (1996) also reported reduction in yield of autumn planted sugarcane when intercropped with mustard. Likewise, yield of mustard was lower in intercropping system than its sole crop. Intercropping of mustard with autumn planted sugarcane gave additional yield of 1.5 t ha^{-1} of mustard without any reduction in sugarcane yield (Singh *et al.,* 1985). Similarly, additional yield of 2.83 q ha^{-1} of mustard at Pantnagar (Kumar, 1983) and 10-16 per cent at Kanpur (Rathi, 1980) was obtained compared to pure crop of mustard. Intercropping of mustard with sugarcane was more remunerative than sugarcane along (Dixit and Mishra, 1991; Gulati *et al.*, 1995 and Shivay and Rathi, 1996).

Singh and Rathi (1984) reported that maximum yield of component crops of potato in mustard and potato intercropping were obtained with nitrogen application of 120 and 160 kg ha^{-1}, respectively. Rathi and Singh (1983) as well as Singh and Verma (1989) registered the highest potato equivalent yield in mustard + potato intercropping with 150 kg N ha^{-1}. Further, Rana *et al.* (2001) observed that potato + staggeredly sown *Brassica carinata* intercropping recorded the highest seed yield of *B. carinata* and potato tuber equivalent yield, respectively.

Mamun *et al.* (2002) intercropped mustard with chilli at different seedling ratios and got higher yield and profit in seedling ratio as 26% mustard + 100% chilli. Wnuk (1998) found that intercropping of pea with tansy phacelia and white mustard had significant effect on decreasing the pea thrips population and got a reverse result of this intercropping for the pests *viz.* pea aphid, pea moth, and pea beetle. Tahir *et al.* (2003) concluded after their experiment that canola was the dominant crop in each intercropping system, and wheat was more competitive followed by linseed than gram and lentil.

3. Effect on Water Use Efficiency

Intercropping of mustard + wheat is a promising one in efficient resource utilization, as component crops have scope to excavate the soil moisture from different layers of soils because wheat being shallow rooted though the mustard has deep root system, besides it also checks the water evaporation from the soil surface (Mandal *et al.*, 1986a, b). Further, Rathore *et al.* (1998) and Khushu *et al.* (2001) found the moisture conservation practices brought about an improvement in water use efficiency of the mustard + lentil intercropping system as compared to control, this was due to the increment in moisture stored by moisture conservation practices and increased availability of soil moisture and also because of the reduction in evapotranspiration losses under mulching. Fertility levels also enhanced the consumptive use, moisture use efficiency and moisture use rate over control, 100% RDF fertility level showed the maximum (10.18 kg ha^{-1} mm^{-1}) moisture use efficiency followed by 50% RDF and control, respectively and this was because of higher seed yield with increased fertility levels (Katiyar *et al.*, 2003 and Prasad *et al.,* 2003). Singh *et al.* (2000) in an experiment at Kashmir valley concluded that the crops extracted greater amount of soil moisture from the top 0-30 cm soil layer than from 30-60 and 60-90 cm soil depth in sole cropping as well as in intercropping systems, it might be due to greater availability of soil moisture in this soil layer, and the existence of maximum root biomass in this soil profile, which resulted in maximum extraction of soil moisture from this profile. He also reported that moisture depletion from deeper layers by brown *sarson* + lentil intercropping system might be due to moisture stress in the upper 0-30 cm soil profile, compelling the roots to go deeper in search of moisture and it explains the reason behind greater depletion of soil moisture from deeper soil profiles and finally, reported intercropping of brown *sarson* either with lentil in 1:4 row ratio or with oat in 1:2 row ratio is a biologically sustainable intercropping system for rainfed temperate conditions of Kashmir valley. Moreover, Singh and Rana (2006) reported that water use efficiency (WUE) and consumptive use were higher in Indian mustard paired row (30/90 cm) + lentil (2 rows) intercropping as compared with pure stands of the component crops.

4. Effect on Land Equivalent Ratio (LER)

Land Equivalent Ratio (LER) indicates the biological efficiency of the mixed/intercropping system and when its value exceeds one, it shows yield advantage of the system over pure crop stand (Willey, 1979a). Yield advantage associated with intercropping of mustard and wheat has been demonstrated (DWR, 1987). LER values calculated from combined intercrops yields of all the mixed/ row proportion treatments have always been higher compared to pure cropping of either wheat or mustard. This indicates greater biological efficiency and justifies the desirability of the mixed/row intercropping treatments (Sharma *et al.*, 1986; Singh and Gupta, 1994 and Singh *et al.*, 1995). However, Francis *et al.* (1978) noticed lower LER values in treatments having 25:75 seed mixture and 1:1 row arrangement of mustard and wheat. They attributed this to the tough early competition that reduced the yield of both the crops. Saxena and Das (1990) observed that intercropping of mustard + wheat in 1:2 row ratio was more efficient than cultivation of either crop in pure stand in terms of LER. Similarly, in another mustard + wheat intercropping experiment at various row ratios *viz.* 1:1, 2:4, 2:6 and 2:10, the LER was maximum (1.57) in 2:6 row ratio and it indicated that on an average, yield similar to that of the pure stand of both the crops can be obtained from 56.5% reduced land area under 2:6 row ratio (Singh *et al.*, 1991). Singh and Gupta (1994) also conducted field experiment on mustard + wheat intercropping at Pantnagar, Uttarakhand and maximum LER of 1.21 was recorded in 2:10 row ratio followed by 1.18 in 2:4 row ratio. However, intercropping of mustard + wheat intercropping 1:1 row ratio proved most inefficient as it recorded the lowest LER of 1.09, even though it registered the yield advantage of 9.0 per cent as observed by Rehman *et al.*(1982). Among the three row intercropping treatments *viz.* 1:1, 1:2 and 1:3, 1:3 mustard + wheat intercropping produced maximum LER at R.S. Pura (Jammu and Kashmir), Faizabad (Uttar Pradesh) and Navsari

(Gujarat). However, 1:2 and 1:1 row ratio of mustard + wheat recorded highest LER values over rest treatments at Pantnagar (U.P.) and Kalyani (West Bengal), respectively (Choudhary and Bhatia, 1992). In a field experiment conducted for three years at west Champaran in Bihar, *B. juncea* cv. Varuna was intercropped with wheat cv. UP 262 in varying row ratio of 1:3, 2:3, 1:6, 2:6, 1:9 and 2:9, the highest mean LER of 1.14 was recorded in 1:9 and 2:6 row combinations (Singh *et al.*, 1995). Similarly, various workers have been reported highest LER values at different row proportions of mustard and wheat from various places *viz.* 1:8 at Ranchi, Jharkhand (Gupta and Pradhan, 1988); 1:3 at Dharwad, Karnataka (Hiremath *et al.*, 1993); either 2:8 or 4:4 row ratio at Niphad, Maharashtra (Patil *et al.*, 1995) and 1:5 row ratio at Varanasi, Uttar Pradesh (Srivastava and Bohra, 2006 and Srivastava *et al*, 2007). However, Sharma *et al.* (1986) reported the highest LER associated with 1:3 mustard and wheat seeds mixture, but the mean LER for different intercropping treatments ranged from 1.18 to 1.25. Comparative studies of sole stand of each yellow *sarson*, *sarson* (*Brassica campestris* L.) and wheat along with two row intercropping treatments *i.e.* 1:1 and 1:3 yellow *sarson* + wheat was carried out by Rahman (1999) on silt loam soil of Bangladesh. Higher LER value was correlated with the higher partial LER values for both the component crops, indicating less competition between them or complementary effect of one crop on the other (Bora, 1999). A number of other workers have estimated the LER in the mustard + wheat intercropping system grown in different row proportions. The LER values have been found to vary widely from 1.01 to 1.32 (Singh *et al.*, 1995; Verma *et al.*, 1997; Srivastava and Bohra, 2006 and Srivastava *et al.*, 2007). Singh *et al.* (2000) observed that the highest land equivalent ratio (LER), area time equivalency ratio (ATER) and effective yield total (EYT) were obtained at 2:6 (mustard + chickpea) row ratio. Mishra *et al.* (2001) also reported similar findings. As the two crops had different life duration so their peak demand for light, moisture and nutrients were varying, producing complementary effects for each other. However, at New Delhi, LER of mustard + lentil intercropping system was less than 1.0 indicating that mustard was competitive to lentil (Saran and Giri, 1985). In sugarcane, LER of mustard with autumn planted sugarcane intercropping system was 52-60 per cent higher over sole crops (Singh *et al.*, 1986).

8. Economics of *Brassica* based intercropping systems

Any intercropping system may not be feasible and acceptable to the farmers unless it gives additional monetary return over component crops in sole stands. Various workers have reported different results under varied conditions. The most of them have found the intercropping of mustard + wheat to be more remunerative over both wheat and mustard in pure stand. Singh and Yadav (1990) observed the complementary effect of mustard + wheat in intercropping system as reflected by higher net return. Srivastava *et al.* (2007) reported that intercropping of mustard and wheat at 1: 5 row ratio gave maximum net profit at Varanasi, (Uttar Pradesh). Intercropping of *toria (Brassica campestris* var. *toria*) with wheat and lentil was more advantages than mixed and sole cropping at Almora, (Uttarakhand), (Kumar *et al.*, 2008). In mustard + chickpea intercropping, maximum net returns in mustard + chickpea intercropping system over sole chickpea were obtained in paired row of chickpea (30/60 cm) + one row of mustard at Hisar (Mehta *et al.,* 1990), 2:1 row ratio at Pantnagar and Kanpur (Bhola, 1991), 2:2 paired planting at Ludhiana (Hedge and Pandey, 1992) and 8:1 row ratio at Faizabad (Singh and Yadav, 1992). The additional benefits from mustard + chickpea intercropping system ranged between Rs. 600 ha^{-1} in Rajasthan to Rs. 2200 ha^{-1} in Haryana (Hedge, 1993). Verma and Srivastava (1987) and Keshwa *et al.* (1988) obtained the maximum net returns in 1:3 and 1:2 planting pattern of mustard + chickpea, respectively. Intercropping one row of mustard after every 5 or 6 rows of chickpea was more remunerative at Durgapur and Jhunjhunu districts of Rajasthan and Rohtak and Jind districts of Haryana (Choudhury, 1991). Mandal *et al.* (1996) reported that Indian mustard var. Vardan + chickpea var. BG 1003 proved to be the best intercropping system in 2: 6 ratio, fetching highest net return owing to higher productivity. Mustard + chickpea (2:6) row ratio also gave the highest net returns and benefit: cost ratio in the finding of Singh *et al.* (2000). At Meerut, (Uttar Pradesh), Abraham *et al.* (2010) was conducted an experiment on chickpea + mustard intercropping and observed net returns and benefit: cost ratio were significantly higher in intercropping of mustard var. B 70 and chickpea var. Avrodhi in 1: 4 row ratio as compared to their sole crops. At Mohanpur, (West Bengal), Indian rape + lentil in 1:1 row proportion gave higher net returns than that of 1:2 or 2:1 row proportion (Mandal *et al.*, 1996).

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