Review Article

Best row ratio combinations of agronomic crops in intercropping system: An Overview

ABSTRACT

The quality of soil and water as well as the preservation of biodiversity are negatively impacted by intensive agricultural systems. A high level of biodiversity regulates how intercropping evolves. Contrastingly, monocultures are used in intensive agriculture systems, along with substantial inputs of chemical fertilizers and pesticides. One strategy for boosting diversity in an agricultural ecosystem is intercropping. With the adoption of intercropping systems, environmental harmony, increased resource use, enhanced quantity and quality of goods, and less damage from pests, diseases, and weeds will mostly improve. Leguminosae family plants are preferable for intercropping even though they fix more biological nitrogen, thus enriches soil fertility. Intercropping is significant in many subsistence or low-input/resource-limited agricultural systems, which are on the periphery of modern intensive agriculture. Thus, by opting suitable combinations of crops with optimum row ratio will be more profitable, ecologically sound and economically viable.

Key Words: Intensive agriculture, intercropping, soil fertility, row ratio.

INTRODUCTION

There are 1.25 billion people in India, and their needs for food and nourishment must be met. To boost productivity, the available land use system should be intensified through a cooperative strategy (Dwivedi *et al.,* 2015). Intensive agricultural practices have a negative effect on biodiversity preservation, soil and water quality, and both. A high level of biodiversity controls the evolution of intercropping. Contrastingly, intensive agriculture systems rely heavily on chemical pesticides and fertilizers and monocultures (Neamatollahi *et al*, 2013).

Due to the rapid increase in population, there is a severe food scarcity in many parts of the world, especially in Asia and Africa. Maximizing the use of limited agricultural land through multiple cropping to boost productivity per unit area of arable land is one potential solution to this issue. (Seran *et al*., 2010 and Khan *et al*., 2014) Additionally, the farming system's diversity is increased, which promotes stability (Mousavi and Eskandari *et al.,* 2011). Since ancient civilization, intercropping—the simultaneous development of two or more crop species in the same field area—has been a common practise all throughout the world. Intercropping offers a chance to utilize and make the most of the environmental resources that are already accessible, such as space, light, and nutrients, as well as to increase crop yield and quality (Hassan *et al.*, 2018). In order to overcome the risk of total crop failure and to enhance the productivity as well as net profit per unit area and per unit time besides increasing the water use efficiency, intercropping cropping of Indian mustard in chickpea can be practiced. (Narayan., 2019). In the low-input and/or high-risk tropics, where intercropping of cereals and legumes is common among smallholder farmers due to the potential of the legume to help solve the issue of diminishing levels of soil fertility, intercropping systems are advantageous to smallholder farmers. Flexibility, profit maximization, risk reduction, soil conservation and development of soil fertility, weed, insect, and disease control, and balanced nutrition are the main motivations for smallholder farmers to intercrop. (Matusso *et al,* 2014). In addition to increased water and nutrient use efficiency.

Intercropping ensures risks against the crop failure due to adverse weather or market fluctuations besides satisfying the dietary requirement of the explosively growing population. Either increasing area under production or raising productivity are methods of increasing output. In general, it is unlikely that more land will be planted only to pulses, oilseeds, or even wheat as the need for land for other crops would only increase. Therefore, increasing crop productivity is the only way to go. In addition to other strategies, intercropping systems, which grow two or more crops simultaneously on the same plot of land, may be crucial, especially in rain-fed environments where monocropping systems pose a greater danger.

Intercropping is known to intercept more solar energy (Yang *et al*., 2010), provide relatively higher production stability (Tsubo *et al*., 2003) , and provide yield insurance during abnormal weather circumstances compared to solitary crops (Willey 1979, Sinha *et al.* 1985, Mandal *et al.*

1991). It also helps boost the efficiency with which water and nutrients are used. The distinctive benefit of intercropping is that it significantly increases overall production throughout time and space without the need of expensive inputs. In particular, microclimatic manipulation is demonstrated to be significantly more limited in single cropping than in intercropping (Stigter and Baldy, 1995).

It is more productive, economic, and secure to intercrop with a certain crop species as opposed to sole cropping. In some regions of India, intercropping pulses with crops like wheat, mustard, cotton, and sugarcane is a widespread technique (Sharma *et al*. 1993). The adoption of compatible crops and their appropriate row proportions are key factors in intercropping performance. Intercrops are grown in two ways: in an additive or replacement series with the primary crops. With replacement series, intercrops are used to replace rows of main crops rather than the whole population of the main crop per unit area as is the case in additive series. A series of agronomic activities that will alter interactions between the species can decide the success of intercrops in comparison to a pure cropping. These procedures include the final density, the planting date, the availability of resources, and the intercropping models (Mazaheri *et al*,. 2006, Gliessman, 1997, Hatfield and Karlen, 1993).

Prospects of intercropping

1. Increase in vertical crop production crop productivity

Intercropping is used globally because it produces more than a single crop from the same plot of land. According to Aladakatti et al. (2011), intercropping sunflower in cotton in a 2:1 row proportion was determined to be more profitable than growing only cotton. With the use of moisture conservation techniques and phosphorus and sulphur fertiliser, the Ethiopian intercropping system of mustard and chickpea produced a greater yield of mustard equivalent than sole mustard and sole chickpea (B Lal et al, 2013). Intercropping systems frequently produce higher yields than single crop systems (Lithourgidis et al, 2007 and Dahmardeh et al., 2009). According to Chaudhary et al. (2020), intercropping sorghum and cowpea (2:1 row ratio) resulted in better yields of green fodder (490 q h-1) and dry fodder (103.3 q h-1) that were equivalent to the yield of sorghum.

Additionally, if there are "complementary effects" between intercropping components, production increases as a result of reduced competition between them (Mahapatra, 2011, Zhang and Li, 2003 and Willey, 1979). However, due to higher CP concentrations in intercrops (16 to 21 g kg-1), crude protein (CP) yields per hectare in intercrop treatments were higher (27.5 to 42.8 percent) than those of monocropped maize (Reta Sánchez et al., 2010). According to Hamdollah and Ahmed (2009), intercropping systems involving maize (Zea mays) and cowpea (Vigna sinensis) significantly boosted dry matter yield as compared to solely growing maize and cowpea.

2. Efficient utilization of available resources

With intercropping, resource usage efficiency can be boosted (Gao et al, 2014 and Nasri et al, 2014). Utilizing the natural resources that are accessible to fields, intercropping (Willey, 1979, Dapaah et al, 2003). legumes and cereal According to Ofori and Stern (1987), intercropping species with various maximum demand periods for environmental resources lengthens the time that resources are exploited, which often results in higher resource use efficiency compared to sole cropping (Chandra et al., 2011). Due to the main crop's and the intercrop's varied uses of natural resources, resources are utilised more effectively than with pure cropping, which raises yield. Jensen (2000). A cereal-legume intercrop would also be advantageous because the constituent crops can use various sources of N. (Chu et al, 2004). The legume can fix N symbiotically if efficient strains of Rhizobium are present in the soil, whereas the cereal may be more competitive than the legume for the soil mineral N. Particularly significant in low input subsistence farming systems, such as those in the East African highlands, is this complementarity of crops in resource utilisation (Getachew et al, 2006). Additionally, two crops that differ in height, canopy, adaptation, and growth habits grow simultaneously with the least amount of competition, greater yield stability throughout the seasons, and better use of available land resources (Bhatti et al., 2006). Wheat-pea intercropping had a noticeably higher radiation usage efficiency than a solo crop, according to Barillot et al. (2014). Due to the interaction between intercrop components and the different levels of competition for the utilisation of environmental resources, intercropping has advantages over pure cropping in terms of crop output (Mahapatra, 2011, Valdez and Fransen, 1986).

3. Reduction of pests, diseases and weeds incidence

A better smothering impact on weeds, pest and disease management may arise from the differed in morphologies, growth patterns, and adaptations of the component crops utilised in intercropping systems (Chu *et al*, 2004). Intercropping increases diversity, which promotes more effective biological pest control (Stephen, 2009). Legumes intercropped with cereals can offer not only nitrogen but also other minerals, soil cover, and habitat for pest predators even they also smother weeds. Monocultures that lack diversity are more prone to weed issues and increased insect pressure. Due in part to monocultures' less diversified insect communities, which include few or no pest predators, the latter issue exists. (Horwith, 1985 and Horrigan *et al*, 2002). Ramert et al. (2002) came to the conclusion that strip cropping, among other intercropping techniques, has the potential to boost crop output by reducing pest breakout. In order to improve the biological control of the wheat aphid (Macrosiphum avenae) by the mite (Allothrombium vatum), Ma et al. (2007) studied strip cropping of wheat and alfalfa. They came to the conclusion that the mean number of mites per parasitized aphid was significantly higher in strip cropping than in wheat monoculture.

It is commonly recognised that weeds can seriously harm crops by competing with them for resources like light, water, nutrients, and space, or by allelopathic effects. Although intercropping patterns are often more efficient at suppressing weeds than monocropping, this is not always the case. When wheat-canola and wheat-conola-pea were intercropped, Szumigalski and Van Acker (2005) noticed stronger weed reduction than they did with their solitary crop. This suggested that intercrops of different crops could work together to reduce weeds. In their 2010 study, Eskandari and Ghanbari examined the effects of intercropping wheat and beans on grain yield, dry matter production, and weed biomass. They came to the conclusion that weed biomass was lower in the intercropping system than in systems with only wheat and beans.

4. Stability and uniformity

When multiple crops are cultivated together, the risk is reduced because if one crop doesn't yield a product, another crop could fill the gap. Multi-cropping systems pose less of an agronomic risk than do pure cropping systems. (Eskandari *et al*, 2009). Yield Farming is a very risky venture, its net return is influenced by a lot of factor that are not within the domain of the farmer to control. Erratic rainfall, outbreak of fires, incidence of pest and disease but to mention few are some of the factors that militates against a successful farming venture. Farmers, especially those with limited resources are very skeptical about the stability of their yield when entering into crop cultivation. Two or more crop grown together compensate each other in terms of yield, therefore incidence of complete crop failure which is usually associated with monocropping is less likely to occur in intercropping systems.

5. Improvement and maintenance of soil fertility

Intercropping is a sort of seasonal rotation that is used on land to maintain soil fertility. Legume has been recommended both as a cereal intercrop and as a standalone crop in order to boost yields and preserve soil health, particularly in degraded soils. (2003) Kumar et al.

Vesicular arbuscular mycorrhizae, for example, can boost microbial diversity when legumes are interplanted with cereals (VAM). VAM is a fungus that plays a crucial role in the transfer of nutrients, such as the transfer of phosphorus to the other crop with which it is intercropped. When one crop can mine different nutritional sources than the other, the relationship with VAM becomes particularly important. According to some data, intercrops have higher P, K, Ca, and Mg availability than monocultures (Vandermeer 1992 and Li et al., 2007). Legumes fix atmospheric nitrogen, which can either be taken up by the host plant or released into the soil by the nodules and taken up by neighbouring plants. The fixed nitrogen may also be released by decomposition of the nodules or leguminous residue after the legume plants die or are ploughed under.

Pulses play a special role in the cropping system, helping to improve soil biodiversity and fix atmospheric nitrogen in the soil while also having a high ability to sequester carbon and a low carbon footprint (Adarsh et al., 2019).

Intercropping upland rice and mung bean enhanced the development of arbuscular mycorrhizas in the upland rice roots. According to the scientists, intercropping boosted mycorrhiza development, which raised total P uptake by 57 percent in rice, total P and N acquisition by 65 and 64 percent, respectively, in mung bean, and nodulation by 54 percent in mung bean. In terms of biomass and nutrient accumulation, wheat/maize and wheat/soybean intercropping clearly outperformed solitary cropping (Li et al. 2001).

Best Row Ratios

Intercropping upland rice and mung bean, per Li et al. (2009), enhanced the development of arbuscular mycorrhizas in the upland rice roots. According to the scientists, intercropping boosted mycorrhiza development, which raised total P uptake by 57 percent in rice, total P and N acquisition by 65 and 64 percent, respectively, in mung bean, and nodulation by 54 percent in mung bean. In terms of biomass and nutrient accumulation, wheat/maize and wheat/soybean intercropping clearly outperformed solitary cropping (Li et al. 2001). Similar to this, Rasool et al. (2011) found that intercropping sugarcane with gramme (111.8 t/ha) was considerably less productive than planting sugarcane alone (130.5 t/ha). Statistics showed that the cane yields in intercropped cane with wheat, lentils, and gramme were comparable to one another. Imran et al. (2000), Santanu and Ray (2003), Singh et al. (2002), and Nazir et al. all noted similar outcomes (2002).

As Sarkar *et al*.(2000) conducted a field experiment as the treatments consisted of 5 sole stands each of chickpea cv. BR 77, linseed cv. T 397' barley cv. BR 32, safflower cv.BYL 652, toria cv. BR32, and intercrop association of chickpea with linseed , barley, safflower or toria in row ratios of 1:1, 2:1, 1:2. Chickpea, linseed, barley and toria were sown in rows 25cm apart, whereas safflower at 45 cm apart under both sole and intercropped stands. The most effective system, which produced the highest chickpea equivalent yield (12.76 q ha-1), gross returns (Rs.10846), net monetary returns (Rs.5346), and benefit:cost ratio, was the intercropping of chickpea and safflower in a 1:1 row ratio (1.97).

In comparison to sole chickpea, sole barley, sole durum wheat, sole mustard, chickpea + barley (3:1) rows, chickpea + durum wheat (3:1) rows, and chickpea + durum wheat (3:1) rows, respectively, the chickpea equivalent yield (2523 kg ha^{-1}), water use efficiency (420.42 kg ha/cm), net return (Rs. 58698/- ha^{-1}), and B:C (3.46) were all significantly It was discovered to be comparable to the chickpea + mustard (4:1) rows cropping system in terms of net return (Rs. 55675/- ha^{-1}), B:C (3.23), water use efficiency (405.0 kg ha/cm), and chickpea equivalent yield (2430 kg ha^{-1}). Meena et al. (2004).

Research on the economic viability and productivity of several wheat-based intercropping systems on the Kaymore Plateau in rain-fed conditions. Three intercropping treatments were used in the experiment, each with a different row percentage of chickpea, linseed, and mustard. The results of the two-year study showed that, in terms of land equivalent ratio (1.36) and gross return (Rs. 54099) and B:C ratio (3.64), the intercropping of wheat and chickpea in 2:2 row proportions outperformed other intercropping or mono-cropping systems. (S.S. Kaushik and T.D. Sharma 2017).

A field experiment was conducted to examine how fertility management affected the intercropping of chickpea and mustard under different row configurations. Eight rows of solo crops of chickpea and mustard in the following ratios: 2:1, 4:1, 6:1, 2:2, 4:2, and 6:2. In both consecutive years, the yield components of chickpea and mustard were highest under a 4:1 (Chickpea + Mustard) row combination, and in terms of fertility management, 125 percent RDF was equal to 100 percent RDF in both years. The 4:1 (Chickpea + Mustard) treatment combination had the highest land equivalent ratio (LER), highest net return (Rs. 87103 ha-1), and benefit cost ratio. This resulted in the highest chickpea equivalent yield (CEY) (4.68). (S.S. Kaushik and T.D. Sharma 2017)

Similar to this, Meena et al. (2018) conducted research at the Govind Ballabh Pant University of Agriculture & Technology's N. E. Borlaug Crop Research Centre during the Rabi seasons of 2015–16 and 2016–17 with the aim of determining the ideal row ratio and nutrient management strategy for a chickpea + linseed intercropping system. The findings showed that solitary cropping produced higher grain/seed, straw/stover, and biological yields of both chickpea and linseed than intercropping combinations did. The higher chickpea equivalent yield (System Productivity) was seen in chickpea + linseed intercropping combinations under both the row arrangements (4:2 and 3:1), and both combinations outperformed solitary linseed by a large margin.

In kharif 1999 and 2000, a field experiment was conducted to determine whether pigeonpea and greengram could coexist in different row spacing and row ratios. In comparison to other row spacings, pigeonpea grown as a single crop at a 45 cm spacing produced 7.0 to 22.5 and 16.6 to 68.5 percent more yield and net return per hectare over the course of two seasons. As evidenced by greater MAl, intercropping of greengram in a 1:2 ratio at 75 cm row spacing in pigeonpea was discovered to be the most profitable combination (4926). In an intercropping system, pigeonpea, which had a competitive ratio of 1.94 to 3.25, outperformed greengram (0.31 to 0.53). (2015) Satish K et al.

According to Tripathi et al. (2016), the wheat:canola intercropping system in a 6:2 ratio had the highest wheat equivalent yield (69.88 q/ha), which was followed by the wheat:mustard intercropping system (62.33 q/ha) in the same ratio.

The results of strip intercropping wheat and maize with a width of 80 cm each were noticed by Yang et al. (2010). Additionally, they noticed greater root growth at the majority of soil depths and yield advantages in an intercropping system as opposed to a single crop.

At the Agricultural Research Station, Dharwad, a three-year field experiment was carried out to examine the impact of intercropping sunflower, castor, and sesame. The results showed that the solitary cotton intercropping system and the cotton + sesame intercropping system produced considerably higher seed cotton yields (SCY) of 1120 kg ha-1 and 1148 kg ha-1, respectively. The cotton + sesame intercropping system produced 993 kg ha-1 (Aladakatti et al, 2011).

Three replications were used in the split-plot design of the experiment. The solo finger millet and groundnut were included in the main plot treatment along with intercropping systems in row ratios of 1:1, 2:1, 3:1, 1:2, and 1:3, while the subplot treatments included three nitrogen levels: 100% RDN, 75% RDN, and 50% RDN + Azospirillum/Rhizobium. The majority of the yield parameters and the yield equivalent to finger millet were higher when finger millet and groundnut were intercropped in a 1:3 row ratio with 100 percent RDN per ha. A single groundnut system produced more total biomass than an intercropping system. The intercropping of finger millet and groundnut in a 1:2 row ratio with 100 percent RDN ha-1 performed better according to economic metrics. However, intercropping finger millet and groundnut in a 1:3 row ratio with 100 percent RDN per hectare produced greater net returns (Rs. 119796 per hectare) and a better B:C ratio (1.92). (Bhagat et al, 2018).

In an additive series with 1:1 and 2:2 row proportions, an experiment was done to determine which maize-based intercropping systems were the most profitable. According to the findings, intercropping increased farmer profits over growing a single crop. The maize + vegetable cowpea (2:2) intercropping system produced the maximum maize grain yield (6830 kg ha-1) and maize equivalent yield (9688 kg ha^{-1}) during rabi 2018-19. Then came maize and black gramme (2:2). In the maize + vegetable cowpea in a 2:2 row ratio, the values of all the competitive functions were greater. The LER, LEC, IA, ATER, and SPI values for this intercropping system were higher at 1.53, 0.52, +13.86, 1.23, and 10.25, respectively. The maize + vegetable cowpea (2:2) intercropping system used in Tamil Nadu's Thamirabarani basin recorded the highest gross return (Rs 1,35,330), net return (Rs 94,842), and B:C (3.34) ratio (Parimaladevi et al, 2019).

A field experiment was carried out at UAS, Hebbal Bangalore, during the Kharif seasons of 2004 and 2005 to examine the performance of the best intercrops when rice (Oryza sativa) is grown aerobically. There were seven intercrops in the experiment, for a total of 14 treatments. Row spacing should be (45 x 20 cm) for single rows and (30/60 cm x 20) for paired rows. The grain production in paired row intercrops was significantly greater (23.7q ha-1) than in standard row (19.7q ha-1) intercropping. In comparison to other intercropping systems, the rice + bhendi intercropping system recorded a significantly higher grain production (27.7 q ha-1) and was statistically comparable to the rice + cluster bean (26.0 q ha-1) intercropping systems. The rice+Ragi intercropping method produced a noticeably lower grain yield (6.8 q ha-1) than other systems (Jadeyegowda et al, 2019).

In order to examine the impact of changing row ratio, mustard variety, and fertility levels on several competitive functions in wheat (Triticum aestivum L.) + mustard (Brassica juncea Czern & Coss) intercropping, a field experiment was undertaken at Varanasi. combining three different wheat and mustard row ratios (8:1, 5:1 and 2:1). The findings showed that whereas mustard's partial LER trended in the opposite direction, wheat's partial LER significantly improved as the row ratio of wheat to mustard increased from 2:1 to 8:1. Despite remaining comparable, the overall LER for the 8:1 and 5:1 row ratios were also noticeably higher than the 2:1 row ratio. The trend for the relative crowding coefficient (RCC) was essentially same. At a 5:1 ratio, when mustard was the most aggressive, wheat was the least competitive. However, maximum wheat equivalent yield (WEY), which was substantially higher than 2:1 row ratio, was generated by a 5:1 row ratio. (Bohra *et al*).

To achieve the goal of this study, six different row ratio combinations with sole cropping of oat and lucerne were evaluated. The planting ratio of 2:1 (oat + Lucerne) in intercropping was significantly superior for all yield and quality measures. However, oat and lucerne cropping alone was found to be superior than a 2:1 (oat + Lucerne) row ratio in terms of yield features (Ninama et al. 2020).

The experimental findings showed that the wheat mustard intercropping method significantly altered wheat yield. The solitary wheat crop that was identical to (wheat-mustard in 3:1 rows) and comparable with (sole wheat) had the maximum seed yield of wheat (3.4 t ha-1) (wheat-mustard in 4:2 rows). As the number of mustard rows increased, wheat yield eventually declined. The highest production of wheat equivalent (5.03 t ha-1) came from (wheat-mustard in 3:1 rows). The treatment that yielded the highest LER was wheat-mustard in 3:1 rows (1.45). Economic study of the various treatments revealed that the highest net return (Rs. 61178.0 ha-1) and BCR (2.04) from the treatment with the highest gross return was (wheat-mustard in 3:1 rows). According to the results of the current study, 3:1 rows of wheat and mustard intercropped demonstrated the best compatibility in terms of yield advantage and financial gain (Biswas et al. 2019).

Singh and Arya (1999) from Ranichauri (Uttaranchal) reported higher net return and B: C ratio under mixed cropping of finger millet + soybean (9:1 seed mixture) as compared to finger millet + rice bean mixed cropping system and sole crop of finger.

Maitra *et al.* (2000) from Shriniketan (West Bengal) reported that intercropping of finger millet + pigeon pea and finger millet + groundnut at 4:1 row proportion recorded higher monetary net returns and benefit:cost ratio than finger millet + green gram, finger millet + soybean and sole finger millet.

Chaudhary *et al.* (2020) revealed that the growth and yield attributes of intercropping system were recorded highest in 3:1 (chickpea + rapeseed) row ratio among all and produced significantly highest chickpea equivalent yield (28.40 q/ha), land equivalent ratio (1.32), net income (Rs 1,01,302/ha) and B: C (2.73) ratio.

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