International Journal of Plant & Soil Science

34(22): 645-654, 2022; Article no.IJPSS.90330
ISSN: 2320-7035

Best Row Ratio Combinations of Agronomic Crops in the Intercropping System: An Overview

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i2231419

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/90330

Review Article

Received 04 June 2022
Accepted 09 August 2022
Published 12 August 2022

ABSTRACT

The quality of soil and water, as well as the preservation of biodiversity, are negatively impacted by intensive agricultural systems. High 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. Intercropping systems improve environmental harmony, increased resource use efficiency, enhance the quantity and quality of goods, and less damage from pests, diseases, and weeds. Leguminosae family plants are preferable for intercropping even though they fix more biological nitrogen, thus enriching 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, opting for suitable combinations of crops with an optimum row ratio will be more profitable, ecologically sound, and economically viable.

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Keywords: Intensive agriculture; intercropping; soil fertility; row ratio.

1. 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 [1]. Intensive agricultural practices harm biodiversity preservation, soil and water quality, and both. Contrastingly, intensive agriculture systems rely heavily on chemical pesticides and fertilizers, and monocultures [2]. Due to the rapid increase in population, there is 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 an important potential solution. [3,4]. The farming system's diversity is increased, which promotes stability [5]. Since ancient civilization, intercropping—the simultaneous development of two or more crop species in the same field area has been a common practice throughout the world. Intercropping offers a chance to utilize 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). To overcome the risk of total crop failure and to enhance 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 [6]. In the low-input and/or high-risk tropics, where intercropping of cereals and legumes are common among smallholder farmers due to the potential of the legume to 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 [7], (Jacques et al., 2022). In addition to increased water and nutrient use efficiency.

Intercropping ensures risks against 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 lands will be planted for pulses, oilseeds, or even wheat as the need for land for other crops would increase. Therefore, increasing crop productivity is the only way to go [8]. 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 rainfed environments where monocropping systems pose a greater danger. Intercropping is known to intercept more solar energy [9], provide relatively higher production stability [10], and provide yield insurance during abnormal weather circumstances compared to solitary crops [11], (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 for expensive inputs. In particular, microclimatic manipulation is demonstrated to be significantly more limited in single cropping than in intercropping [12,13].

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 [14]. 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 pure cropping. These procedures include the final density, the planting date, the availability of resources, and the intercropping models [15,16,17]. This paper is a detailed review of different row ratio combinations of different agronomic crops here we try to explain a suitable row ratio combination for optimum production, higher net returns, efficient utilization of available farm resources. Thereby, fulfill the farmer’s need and they can live their life happily.

2. PROSPECTS OF INTERCROPPING

2.1 Increase in Crop Production

Intercropping is used globally because it produces more than a single crop from the same plot of land. According to Aladakatti et al*.*, [18], intercropping sunflowers 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 sulfur fertilizer, 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 [19,20]. According to Chaudhary et al*.,* [21], 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}) sorghum equivalent yield, net returns (Rs. 55,597 ha^{-1}) and benefit cost ratio (BC ratio) (2.30). Intercropping of sorghum and cowpea with 2:1 row ratio was found economically viable with higher green fodder yield and net returns.

Additionally, if there are "complementary effects" between intercropping components, production increases as a result of reduced competition between them [22,23,11]. 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.

2.2 Efficient Utilization of Available Resources

With intercropping, resource usage efficiency can be boosted [24,25]. Utilizing the natural resources that are accessible to fields, intercropping [11]. Legumes and cereal According to Ofori and Stern [26], 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 [27]. Due to the main crop's and the intercrop's varied uses of natural resources, resources are utilized more effectively than with pure cropping, which raises yield Jensen [28]. A cereal-legume intercrop would also be advantageous because the constituent crops can use various sources of nitrogen; N [29]. 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 utilization (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., [30]. Due to the interaction between intercrop components and the different levels of competition for the utilization of environmental resources, intercropping has advantages over pure cropping in terms of crop output [22,31].

2.3 Reduction of Pests, Diseases, and Weeds Incidence

A better smothering impact on weeds, pests, and disease management may arise from the differences in morphologies, growth patterns, and adaptations of the component crops utilized in intercropping systems [29]. Intercropping increases diversity, which promotes more effective biological pest control [32]. Legumes intercropped with cereals can offer not only nitrogen but also other minerals, soil cover, and habitat for pest predators even though they also smother weeds. Monocultures that lack diversity are more prone to weed issues and increased insect pressure. The latter problem emerges in part because insect communities in monocultures are less diverse and include little or no pest predators [33,34]. Ramert et al*.,* (2002) concluded that strip cropping, among other intercropping techniques, has the potential to boost crop output by reducing pest breakout. To improve the biological control of the wheat aphid (*Macrosiphum avenae*) by the mite (*Allothrombiumvatum*), Ma et al*.,* [35] studied strip cropping of wheat and alfalfa. They concluded that the mean number of mites per parasitized aphid was significantly higher in strip cropping than in wheat monoculture.

It is commonly recognized 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-canola-pea were intercropped, Szumigalski and Van Acker

[36] 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 concluded that weed biomass was lower in the intercropping system than in systems with only wheat and beans.

2.4 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 pure cropping systems. Eskandari et al., [37] Yield Farming is an extremely hazardous business since a lot of variables outside of the farmer's control affect the net return. Unpredictable rainfall, fire outbreaks, pest and disease occurrence, to name a few, are some of the variables that work against a prosperous farming enterprise. When beginning crop cultivation, farmers, especially those with low means, are highly doubtful about the consistency of their production. 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.

2.5 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 to boost yields and preserve soil health, particularly in degraded soils [38].

Vesicular arbuscularmycorrhizae, 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 [39]. 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 neighboring plants. The fixed nitrogen may also be released by the decomposition of the nodules or leguminous residue after the legume plants die or are plowed under. Cereal-legume intercropping has the potential to combat the worsening impacts of climate variability in arid region agriculture [40]. 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 [41].

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

3. BEST ROW RATIOS

Intercropping upland rice and mung bean, per Li et al., [39], enhanced the development of arbuscularmycorrhizas in the upland rice roots. According to the scientists, intercropping boosted mycorrhiza development, which raised total P uptake by 57% in rice, total P and N acquisition by 65 and 64%, respectively, in mung bean, and nodulation by 54% in mung bean. In terms of biomass and nutrient accumulation, wheat/maize and wheat/soybean intercropping outperformed solitary cropping (Li et al., 2001). Similar to this, Rasool et al., [42] found that intercropping sugarcane with gram 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 gram were comparable to one another. Imran et al., [43], Santanu and Ray [44], Singh et al., [45], and Nazir et al., all noted similar outcomes [46].

As Sarkar et al., [47] 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., [48].

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 [49].

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) [49].

Meena et al., [48] conducted research at the GovindBallabh Pant University of Agriculture & Technology's N. E. Borlaug Crop Research Centre during the Rabi seasons of 2015–16 and 2016–17 to determine 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 the Fall season of 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 throughout two seasons. As evidenced by greater MAI, 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) [50].

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., [9]. 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.

Foxtail millet + niger (2:4) outperformed exclusively foxtail millet and little millet in terms of plant height, total dry matter production, grains weight per 0.5-m row length (93.33 g), and test weight (3.41 g). The highest yield of little millet was obtained when intercropping with sesame in a 2:4 row ratio, while the highest yield of foxtail millet was obtained when intercropping with niger in a 2:4 row ratio (762 kg ha-1) (562 kg ha-1). The maximum system production was achieved in foxtail millet + niger intercropping systems with a 2:4 row ratio (1916 kg ha-1) and was followed by systems with a 1:2 row ratio. Foxtail millet intercropped with niger in a 2:4 row ratio had the highest system profitability in terms of net returns and the benefit-cost ratio (28,642 ha-1 and 2.65, respectively), followed by foxtail millet with niger in a 1:2 row ratio. As a result, we draw the conclusion that the foxtail millet + niger (2:4) intercropping system is effective and beneficial [51].

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) [52].

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 gram (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 [53].

To examine the impact of changing row ratio, mustard variety, and fertility levels on several competitive functions in wheat (*Triticumaestivum* 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 the 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 the 2:1 row ratio, was generated by a 5:1 row ratio [54].

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 were found to be superior to 2:1 (oat + Lucerne) row ratio in terms of yield features [55].

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).

The 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 [56].

Singh and Arya [57] 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 the finger.

Maitra et al*.,* (2000) from Shriniketan (West Bengal) reported that intercropping of finger millet + pigeon pea and finger millet + groundnut at a 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.

The treatment T5: sesame + groundnut (1:3) yielded the highest production of oil (594 kg/ha) among the intercropping combinations. According to the study, groundnut populations that were 50% or above reported significantly greater oil yields when sesame and groundnut were intercropped. The treatments T3: sesame + groundnut (1:1), T4: sesame + groundnut (1:2), T5: sesame + groundnut (1:3), T7: sesame + groundnut (2:2), T8: sesame + groundnut (2:3), and T11: sesame + groundnut had beneficial land equivalent ratios, relative crowding coefficients, and monetary advantages (3:3). In order to reap the benefits of intercropping throughout the summer, the study found that sesame may be intercropped in groundnut with a proportion of at least 50% of legumes (groundnut) [58].

Chaudhary et al*.,* [59] revealed that the growth and yield attributes of the intercropping system were recorded highest in the 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 [60-69].

4. CONCLUSION

This entire review informs us of the significance of the intercropping system and the combination of appropriate row ratios about various crops. By choosing this method, yield performance will be increased as each plant receives adequate space, sunlight, etc. Additionally, complementary interation between the crops will benefit both crops in terms of nitrogen fixation, protection (guard crops), insect repellent, weed suppression, moisture retention, etc. also efficient use of the resources that are available It is possible to boost productivity and profitability in intercropping systems while also improving resource use efficiency, environmental sustainability, food security, nutritional security, and socioeconomic status.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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