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Effect of Organic Manures and Biofertilizers on Productivity and Profitability of Wheat + Chickpea Intercropping System

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ABSTRACT

Background: The integration of intercropping systems and organic amendments can enhance crop productivity and soil health. This study aimed to assess the performance of wheat and chickpea under different row ratios and organic amendment treatments to identify economically viable options for achieving higher productivity.

Methods: A field experiment was conducted from 2020 to 2023 at School of Agriculture Research Farm, Lovely Professional University, Phagwara, Punjab. The experiment was conducted in spilt plot design and replicated thrice. The treatments comprised of different row ratios as main plot treatment and organic amendments as sub plot treatment.

Result: Wheat intercropped with chickpea in the row ratio of 3:1 supplied with FYM 5 t ha^{-1} + Poultry manure 2 t ha^{-1} + Azotobacter + PSB was found to be suitable economically viable options for realizing higher productivity. This integrated nutrient management approach increased crop yield but also helped promote sustainability in agriculture by supporting interactions between wheat and chickpea, ensuring soil fertility for a long period and economic profitability.

Key words: Azotobacter, Chickpea, Intercropping systems, Organic amendments, Productivity, Profitability, Wheat.

INTRODUCTION

Wheat is the second most important crop after rice in terms of cultivation area and production. It is predominantly grown in the Indo-Gangetic Plains with smaller proportions cultivated in other regions (Bhatt *et al.,* 2021). Punjab is a leading wheat-producing state, with cultivation predominantly occurring under irrigated conditions during the *rabi* season (Ramadas *et al.,* 2019). Wheat is a rich source of carbohydrates (78%), protein (11-12%) and gluten, which is ideal for bakery products and traditional Indian flatbreads. Globally, wheat flour accounts for 80-85% of processed grains (Chaudhary *et al.,* 2021). According to FAO estimates, global wheat demand will reach 840 million tons by 2050 (Dadrasi *et al.,* 2023). Chickpea, the primary pulse crop of India, is mostly grown in the *rabi* season, thriving in warm temperate and semi-arid regions (Maji *et al.,* 2019). Originating from Southwest Asia, chickpea is a leguminous crop that requires minimal water due to its drought-tolerant morphological traits (Asati *et al.,* 2022). It is highly nutritious, containing essential amino acids (leucine, lysine, valine, isoleucine and phenylalanine), protein (21%), dietary fiber (6%) and key minerals like calcium (49-53 mg/100 g), phosphorus (340 mg/100 g), magnesium (140 mg/100 g) and iron (7 mg/100 g) (Purewal *et al.,* 2023).

The increasing demand for sustainable agriculture has led to the adoption of cropping systems like crop rotation, agroforestry, relay cropping and intercropping. Among these, cereal-pulse intercropping systems, such as wheat-chickpea was effective in conserving soil, suppress weeds (Kumar *et al.,* 2023) and improving resource use efficiency (Rahman *et al.,* 2022). Intercropping also optimizes nitrogen utilization (Nasar *et al.,* 2023) and enhances crop productivity and quality (Maitra *et al.,* 2019). Chickpea benefits wheat by fixing atmospheric nitrogen, reducing nitrogen deficiencies in the soil and increasing nitrate availability in the root zone. Chickpea also contributes organic matter through leaf shedding and residue mineralization, enriching the soil for subsequent crops (Ghosh *et al.,* 2019).

Biofertilizers, comprising beneficial microorganisms like Rhizobium, Azotobacter, Azospirillum and Phosphate-Solubilizing Bacteria (PSB), enhance nutrient (Nosheen *et al.,* 2021). These eco-friendly inoculants fix nitrogen, solubilize phosphorus and improve plant growth by synthesizing growth regulators such as auxins, gibberellins and cytokinins (Kumar *et al.,* 2022). Soil health is a major

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concern among the various impacts faced. As a result, there is a growing interest in exploring the possibility of replacing chemical fertilizers with organic alternatives that are both cost-effective and environmentally friendly. Organic sources of nutrients offer essential nutrients and enhances soil quality by stimulating microorganisms. Biofertilizer inoculation further promotes crop growth through nitrogen fixation, phosphate solubilization and the synthesis of growth hormones, vitamins and siderophores (Timofeeva *et al.,* 2023). Research has shown that biofertilizers have a positive impact on agricultural productivity and soil fertility. Combining biofertilizers with organic manures could prove to be a practical approach for maintaining crop yields (Singh *et al.,* 2020). Considering the decline in soil organic matter and its implications on soil health and productivity, the integrated application of organic nutrient management practices becomes crucial for enhancing yields and income. Organic manures have more porosity resulting in higher water holding capacity which is of great significance (Wang *et al.,* 2017). Further organic manures release both macro and micro nutrients in optimum amounts as required by the plant (Shaji *et al.,* 2021). Soil physical conditions and fertility levels increase with application of organic manures as they help in increasing microbial diversity and subsequent enzymatic activities in rhizosphere leading to release of nutrients in right proportions (Cui *et al.,* 2018). Combining biofertilizers with organic amendments such as FYM, vermicompost and poultry manure has shown remarkable improvements in the growth, yield and quality of wheat and chickpea in intercropping systems. Organic amendments, combined with intercropping systems and biofertilizer use, hold immense potential for enhancing wheat and chickpea production in India, particularly in Punjab. Keeping the above facts in view, an experiment was conducted to explore the potential of increasing cereal and pulse production through an intercropping system. The study aimed to determine the feasibility of optimizing crop spatial arrangement and nutrient management practices to maximize productivity while maintaining soil health.

MATERIALS AND METHODS

The experiment was conducted at Agriculture Research Farm, Department of Agronomy, Lovely Professional University, Phagwara (Punjab) during *rabi* season of 2020-23. The experimental soil was sandy loam in texture with pH. The experiment was laid out in spilt plot design and replicated thrice. The experiment comprised of different row ratios *viz.* Sole Wheat, Wheat + Chickpea (2:2) and wheat + chickpea (3:1) as main plot treatments and organic amendment treatments *viz.* Control, FYM 10 t /ha + VC 6 t/ha + *Azotobacter* + PSB, FYM 5 t /ha+ PM 2 t /ha+ Azotobacter + PSB and VC 3 t/ ha + PM 2 t/ha + Azotobacter + PSB as sub plot treatments. Sole chickpea was not included in the main plot treatments as the study aimed to assess the potential of wheat-dominant systems under various intercropping geometries. The wheat variety 'PBW 550' was sown with a seed rate of 100 kg/ha at 10 cm row spacing and the chickpea variety GNG-469 was sown with a seed rate of 80 kg/ha at 20 cm row spacing. The experimental soil was low in organic carbon and available nitrogen and high in available phosphorus and potassium with bulk density of 1.08 g/cm^3. Wheat and chickpea crops were fertilized with recommended doses of fertilizers. The intercropping was done using the replacement series method where wheat + chickpea (2:2) had 50% wheat population and 50% chickpea population and wheat + chickpea had 90% wheat population and 10% chickpea population.

Data pertaining to yield and yield attributes of wheat and chickpea were recorded at harvest. The data underwent analysis of variance (ANOVA) in a split plot design and the results were presented at a significance level of 5% (Gomez and Gomez, 1984). Critical difference (CD) values were calculated to compare various treatment means accordingly. The calculation of cultivation expenses involved determining the prices of inputs used, given in Indian rupees per hectare. Economic values for grain/seed and straw yield were estimated using the minimum support prices set by the Government of India for wheat and chickpea. Seed yield of chickpea was converted to wheat equivalent yield, based on the prevailing market prices of the commodities by the following formula:

$$\text{Wheat equivalent yield} = \frac{\text{Seed yield of chickpea (t ha}^{-1}) \times \text{Price of chickpea (` t}^{-1})}{\text{Price of wheat (` t}^{-1})}$$

The data obtained from various yield and economical attributes were analysed statistically by using OPSTAT software.

RESULTS AND DISCUSSION

Yield attributes and yield of wheat

Evaluation was conducted of the effects of cropping geometry and organic amendments on wheat yield and yield attributes, where significant differences in yield performance were found between treatments. Sole wheat cropping was the most productive for grain as well as straw yield across all intercropping systems. The maximum potential in sole wheat is brought by optimal land use management and without crop competition with results of better availability for nutrient, water, as well as light (Panhwar *et al.,* 2019). The presented data Table 1 correspond to Liu *et al.* (2023) that concluded sole crops allow to reach maximum crop yields since the crop encounter less limitations for growth. The observed high yield in sole wheat is in agreement with previous researches, where monoculture systems showed higher productivity compared to intercropped systems.

However, the intercropping systems, especially wheat + chickpea (3:1 ratio), offered several ecological and agronomic advantages, such as better soil health and

Table 1: Effect of cropping systems and organic amendments on yield attributes and yield of wheat.

	No of spikes m^2	Spike length cm $spike^{-1}$	Spikelet's $spike^{-1}$	test weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	H.I index (%)
Cropping system								
Sole wheat	327.75	12.209	19.693	42.008	54.55	77.65	132.2	41.153
2:2 Wheat +chickpea	197.667	12.739	20.302	41.376	35.708	48.867	84.575	42.184
3:1 Wheat + chickpea	256.583	12.749	20.302	42.598	52.05	72.642	124.692	41.608
SEm (±)	0.833	0.048	0.084	0.213	0.125	0.166	0.167	0.127
CD (5%)	3.36	0.192	0.337	0.859	0.506	0.668	0.675	0.513
Organic amendments								
Control	229.88	11.389	17.96	40.821	39.056	57.911	96.967	40.402
FYM 10 t ha^{-1} + V.C 6 t ha^{-1} + Azotobacter + PSB	271.33	12.816	20.514	42.046	50.167	70.133	120.3	41.838
FYM 5 t ha^{-1} + P.M 2 t ha^{-1} + Azotobacter + PSB	265.88	13.160	21.182	43.19	51.189	68.533	119.722	42.531
V.C 3 t ha^{-1} + P.M 2 t ha^{-1} + Azotobacter + PSB	265.88	12.899	20.738	41.919	49.333	68.967	118.3	41.822
SEm (±)	0.455	0.041	0.191	0.389	0.131	0.188	0.24	0.106
CD (5%)	1.362	0.123	0.572	1.166	0.391	0.562	0.719	0.319

FYM= Farm yard manure, V.C= Vermicompost, P.M= Poultry manure.

nutrient cycling. The 3:1 intercropping system, where 75% of the area was allocated to wheat, performed better than the 2:2 intercropping system, where 50% of the area was allocated to wheat. The beneficial effect of chickpea to soil fertility through nitrogen fixation will therefore be the major reason behind the higher productivity of the 3:1 system for the growth of the wheat crop. This is consistent with Khan *et al.* (2020), which reported that leguminous crops such as chickpea have a significant role in the improvement of soil fertility due to the atmospheric nitrogen fixing, thereby increasing the companion crops such as wheat growth.

The highest spike density in sole wheat was obtained with the organic treatment especially in FYM (10 t ha^{-1}) + vermicompost (6 t ha^{-1}) + Azotobacter and PSB. Organic amendments have been reported to improve soil structure, nutrient availability and microbial activity that results in better plant growth (Chen *et al.,* 2021). These organic management resulted in improved soil properties directly benefiting wheat through their contribution to nutrients availability for better root growth and hence its growth. The intercropping, especially chickpea-based systems, produced somewhat lower spike density attributed to lower density of the wheat plants. Nonetheless, the positive role that chickpea can perform in the nitrogen-fixation process and improving the quality of the soil is, therefore, recognized; chickpea enhances fertility through the growth of wheat plants (Kebede, 2021).

In intercropping system, wheat + chickpea was longest in spike length with the ratio of 3:1. This will further support the idea that intercropping systems enhance plant characteristics when combined with proper nutrient management. Results are in agreement with Kumar *et al.* (2020), who stated that positive impact upon the spike length could be affected by intercropping system when efficient plant spacing with proper nutrient management is achieved. The organic amendments, FYM (5 t ha^{-1}) + poultry manure (2 t ha^{-1}) + *Azotobacter* and PSB, improved the elongation of the spike as a result of better nutrient supply in terms of macro and micronutrients in the soil.

The number of spikelets per spike was greater in intercropping systems, especially in the 3:1 and 2:2 ratios. This is due to the balanced spacing and improved nutrient uptake from organic amendments, which created better growth conditions for the wheat plants. Such improvements in the number of spikelets under intercropping systems have been reported in earlier studies (Qiao *et al.,* 2021; Sheha *et al.,* 2022). The organic amendments, including poultry manure and biofertilizers, increased the number of spikelets by enhancing phosphorus availability and improving soil fertility.

Test weight, yet another indicator of grain quality, was recorded to be the highest with the intercropping systems 3:1. The beneficial interaction probably between organic inputs like FYM and poultry manure and biofertilizer might have further enhanced test weight. Improved soil fertility is a product of those inputs, thus bettering grain development for higher test weight. The same outcome was reported by

Table 2: Effect of cropping systems and organic amendments on yield attributes and yield of chickpea.

	No. of pods plant^{-1}	No. of seeds pod^{-1}	No. of seeds plant^{-1}	Seed index weight (g 100^{-1} seed)	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	Biological yield (q ha^{-1})	H.I index (%)
Cropping system								
Sole wheat	-	-	-	-	-	-	-	-
2:2 Wheat +chickpea	66.913	1.059	71.19	30.383	10.683	32.817	43.5	24.377
3:1 Wheat + chickpea	65.052	1.09	70.135	29.9	5.025	16.658	21.683	22.939
SEm (±)	0.3	0.004	0.13	0.034	0.038	0.048	0.06	0.134
CD (5%)	1.211	0.015	0.524	0.136	0.152	0.192	0.242	0.539
Organic amendments								
Control	45.16	1.001	49.05	28.15	5.05	18.85	23.90	20.948
FYM 10 t ha^{-1} + V.C 6 t ha^{-1} + Azotobacter + PSB	71.107	1.064	75.60	30.36	7.73	25.15	32.88	23.607
FYM 5 t ha^{-1} + P.M 2 t ha^{-1} + Azotobacter + PSB	75.27	1.033	77.66	30.95	9.15	28.93	38.08	24.187
V.C 3 t ha^{-1} + P.M 2 t ha^{-1} + Azotobacter + PSB	72.38	1.110	80.33	31.10	9.48	26.01	35.50	28.890
SEm (±)	0.311	0.008	0.439	0.035	0.03	0.099	0.095	0.124
CD (5%)	0.932	0.025	1.314	0.104	0.089	0.296	0.285	0.372

FYM= Farm yard manure, V.C= Vermi compost, P.M= Poultry manure.

Mukhtiar *et al.* (2018), wherein they stated that organic amendments improved phosphorus availability by enhancing nutrient availability, consequently improving wheat grain quality.

The pattern followed for biological yield was the same as that followed by grain and straw yield, where sole wheat exhibited the highest biological yield, as it should be. Intercropping systems, especially chickpea-based ones, exhibited lower biological yields but still provided great ecological and agronomic benefits, including increased nitrogen fixation and improved root growth, which is good for long-term soil health and sustainability (Kumawat *et al.,* 2022; Yu *et al.,* 2022).

The highest straw yield was recorded in sole wheat, which indicated the full exploitation of available land space. However, the intercropping systems, especially wheat + chickpea, had slightly lower straw yields, which might be due to competition between the two crops for light, water and nutrients. Organic amendments enhanced biomass production, which led to better straw yield than control treatments (Singh *et al.,* 2022).

The highest harvest index was in the 2:2 intercropping system followed by the 3:1 system and sole wheat. Higher harvest index in intercropped systems implies that intercropping systems, through improved resource use efficiency, resulted in better dry matter partitioning to the grain. Organic treatments, especially those involving FYM in association with poultry manure added with biofertilizer, were very crucial toward improving resource use efficiency toward better dry matter accumulation and grain production efficiency improves (Garg *et al.,* 2024).

Sole wheat resulted in higher grain yields, whereas intercropping systems, especially those of wheat + chickpea, gave several ecological and agronomic benefits with better soil fertility, enhanced resource use efficiency and increased nitrogen fixation. The yield attributes of wheat were strongly improved by organic amendments, both in the sole as well as intercropping systems, which makes organic amendments a promising option for sustainable wheat production. These findings support the potential of integrating organic farming practices with intercropping systems to improve crop productivity while promoting soil health and sustainability.

The experimental results indicate that the 2:2 wheat + chickpea intercropping system outperformed the 3:1 ratio in terms of several yield attributes and overall yield. Organic amendments played a crucial role in enhancing the growth and productivity of chickpea, with the combination of vermicompost (3 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB showing the most consistent improvements across all yield parameters.

Yield attributes and yield of chickpea

The highest number of pods per plant was observed in the 2:2 wheat + chickpea intercropping system. Organic treatment FYM 5 t ha^{-1} + poultry manure 2 t ha^{-1} + Azotobacter + PSB performed better than others. This result Table 2

has demonstrated that organic amendments have enhanced branch development and photosynthate translocation, which is necessary for pod formation. With intercropping chickpea, an increased pod number may be explained by the higher area under cultivation for the crop, decreased competition by wheat and enhanced soil fertility resulting from organic inputs. Results in line with those of Singh and Aulakh (2017), which indicate that the organic treatment favors pod production in legumes. Similar trends have been documented by Raza *et al.* (2023), Singh *et al.* (2019) and Devi *et al.* (2024) who have also recorded an increase in pod number through organic amendments.

The 2:2 wheat + chickpea intercropping system was also highly favorable to the number of seeds per pod and number of seeds per plant. The highest seed number per pod was recorded by vermicompost (3 t ha^{-1}) + poultry manure (2 t ha^{-1}) + *Azotobacter* + PSB followed by FYM (10 t ha^{-1}) + vermicompost (6 t ha^{-1}) + Azotobacter + PSB. These treatments substantially outgrew the control and demonstrated the synergistic interaction between organic amendments and biofertilizers for enhancing seed development. In addition, the increase in seeds per plant was observed in the same treatments as above, reflecting enhanced nutrient availability and better plant growth. This result is supported by the findings of Alhammad and Seleiman (2023), Bhardwaj *et al.* (2024) and Coulibaly *et al.* (2023), who mentioned that organic treatments and biofertilizers improve seed formation in legumes.

The seed index, expressed as weight per 100 seeds, was significantly higher in the 2:2 intercropping system compared to the 3:1 ratio. Among the organic treatments, the combination of vermicompost (3 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB produced the highest seed index, followed by FYM (5 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB. The improvement in seed index could be due to the better uptake of nutrients, retention of moisture and fixation of phosphorus due to organic amendments. These findings are in line with Amadou *et al.* (2021), Ullah *et al.* (2021) and Agegnehu *et al.* (2016), who reported that seed quality and yield in intercropped legumes were improved by organic inputs.

Grain yield was considerably higher in the 2:2 wheat + chickpea intercropping system compared to the 3:1 system; the highest yield was, however, recorded under organic treatment of vermicompost (3 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB. The results, in terms of yield improvements can be traced to the better availability of nutrients and structure of soil that was improved by organic treatments for growth and formation of grain by chickpea. Stover yields show similar trends as in previous studies where the 2:2 intercrop performed much better than the 3:1 ratio. The stover yield was the maximum when FYM (5 t ha^{-1}) + poultry manure (2 t ha^{-1}) + *Azotobacter* + PSB were given. Organic amendments led to a better nutrient cycling and higher biomass production, thereby boosting the overall crop productivity. The results of these investigations are in agreement with those of Singh *et al.* (2022), Kumar *et al.* (2020) and Roohi *et al.* (2022), which reported that organic amendments promoted yield performance in intercrop systems.

The highest biological yield was recorded in the 2:2 wheat + chickpea system, where it was significantly higher than that in the 3:1 ratio. The combination of FYM (5 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB proved to be the most effective organic treatment. This result can be attributed to the improved nutrient availability and soil structure provided by organic amendments, which promoted both grain and stover production. The harvest index, which is the ratio of grain yield to biological yield, was also significantly higher in the 2:2 intercropping system than in the 3:1 system. Vermicompost (3 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB resulted in the best performance and indicated that organic amendments contribute towards better partitioning of biomass towards grain production. These results are in line with Celestina *et al.* (2019), who reported the application of organic amendments that improved the efficiency of harvesting.

The WEY of the 3:1 intercropping system was much higher and FYM (5 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB was the best treatment. This suggests that both crops in the intercrop have benefits from shared resources but also highlights the fact that the 2:2 system was still able to yield more chickpeas. The reason for this might be that this system might have been more productive in general. This result is similar to that of Bedoussac *et al.* (2015), who report increased crop productivity due to intercropping with organic inputs.

The 2:2 wheat + chickpea intercropping system with organic treatments consisting of vermicompost, poultry manure and biofertilizers significantly improved the yield attributes as well as overall crop productivity. Such results will serve to emphasize the possibility of enhancing intercropping systems as well as organic amendments toward improved resource utilization, fertility gain in soils and agroecological sustainability in crops. Results support growing lines of evidence showing that organic agriculture enhances crop yield and quality.

Wheat equivalent yield (t ha^{-1})

Both the intercropping systems and the organic amendments significantly influenced the wheat equivalent yield. Wheat + chickpea 3:1 row ratio resulted in the highest yield with nearly 1.08% greater yield than the wheat + chickpea 2:2 row ratio that resulted from intercropping systems with an overall benefit as illustrated in Table 3. In respect to organic amendment, FYM (5 t ha^{-1}) + poultry manure (2 t ha^{-1}) + Azotobacter + PSB recorded highest yield at par of each individual treatment at a level of 2.95 t/ha with significant higher compared to the control plot of 39.61% due to growth promoting substance secretion from the organic amendment, thus root and nutrient assimilation will improve leading towards a better yield.

Economics of wheat and chickpea intercropping

The cost of cultivation is the most significant factor in determining agricultural productivity and economic viability. It is divided into Cost A, which consists of hired labor, machinery, inputs and miscellaneous charges; Cost B, which adds land rental and working capital interest; and Cost C, which incorporates family labor costs. The inputs must yield a commensurate return to ensure profitability. Higher returns compared to the cultivation cost are indicative of economic success (McArthur and McCord, 2017).

In the current study, the highest cultivation cost (` 1,18,739) was recorded for wheat + chickpea intercropping in a 2:2 ratio under the organic treatment of FYM 10 t ha$^{-1}$ + VC 6 t ha$^{-1}$ + Azotobacter + PSB. The other intercropping ratios and the pure wheat treatment showed similar patterns with costs ranging from ` 1,15,474 to ` 1,18,591 (Table 3). These costs reflected higher input expenses associated with applying organic amendments. Such expenses are necessary in the analysis of financial returns for adopting organic practices (Nemes, 2009).

On the contrary, control plots had significantly less cultivation cost, ranging from ` 65,255 to ` 68,520. This is because organic amendments were absent, which otherwise could have been costly; thus, conventional agricultural systems have a cost-saving potential. However, the trade-off with conventional systems is lesser yield and reduced environmental sustainability over time (Rosa *et al.,* 2019).

Gross returns, a direct reflection of the monetary value gained from crop yields, were significantly higher for the intercropping systems, with the 3:1 and 2:2 ratios of wheat and chickpea. The organic treatments also showed superior returns and FYM 5 t ha^{-1} + PM 2 t ha^{-1} + Azotobacter + PSB had the highest returns. These returns were closely followed by VC 3 t ha^{-1} + PM 2 t ha^{-1} + Azotobacter + PSB (El-Mehy and Mohamed, 2018). The intercropping systems are able to provide higher gross returns compared to the sole crop by allowing the complementary effects of chickpea in the process of nitrogen fixation as well as improved solar radiation interception, which enhances photosynthesis for both crops (Dwivedi *et al.,* 2016).

The net returns obtained by subtracting the costs of cultivation from the gross returns indicated that the ratio 3:1 for wheat + chickpea intercropping gave far greater net returns compared with the 2:2 ratio and monocropped wheat. The best net returns from the organic treatments were furnished by FYM 5 t ha^{-1} + PM 2 t ha^{-1} + *Azotobacter* + PSB, thus strengthening further the profitability of the organic farming systems. However, FYM 10 t ha^{-1} + VC 6 t ha^{-1} + Azotobacter + PSB treated plots showed a high net return with the highest increase in yields but was relatively lower due to high input costs. These results are in keeping with other studies that indicated the economic benefits of intercropping systems over sole cropping. Chen *et al.* (2019) have indicated that intercropping systems can increase the profitability by a considerable percentage, especially when combined with organic amendments. These results further indicate the economic viability of incorporating leguminous crops like chickpea into intercropping systems as it will help improve fertility of the soil and avoid chemical fertilizers.

The Benefit-Cost (B:C) ratio, a critical measure of economic efficiency, was notably higher for the 3:1 wheat + chickpea intercropping ratio than for the 2:2 ratio and sole wheat. Among the organic treatments, FYM 5 t ha^{-1} + PM 2 t ha^{-1} + Azotobacter + PSB outperformed others, yielding the highest B:C ratio. This suggests the economic feasibility of the application of organic amendments with intercropping systems, enhancing not only productivity but also sustainability in the environment (Glaze-Corcoran *et al.,* 2020). Maize-legume intercropping enhanced grain yield, stover yield, MEY and B:C ratio, with pendimethalin 30% EC @ 1.5 kg a.i./ha exerting effective weed control

Table 3: Effect of cropping systems and organic amendments on wheat equivalent and economics.

	Wheat equivalent yield (q/ha)	Gross returns (Rs. ha^{-1})	Cost of cultivation (Rs./ha)	Net returns (Rs. ha^{-1})	B:C ratio
Cropping system					
Sole wheat	52.4	Rs.1,24,819.50	Rs.86,150.52	Rs.38,736.56	1.492
2:2 Wheat +chickpea	63.37	Rs.1,42,323.10	Rs.89,410.42	Rs.52,912.66	1.633
3:1 Wheat + chickpea	67.8	Rs.1,42,739.30	Rs.89,267.34	Rs.58,472.03	1.697
SE m (±)	0.57	388.876	-	394.467	0.005
CD p=(0.05)	2.35	1,567.81	-	1,590.35	0.019
Organic amendments					
Control	47.994	Rs.1,09,558.70	Rs. 67,382.66	Rs.42,176.01	1.626
FYM 10 t ha^{-1} + V.C 6 t ha^{-1} + Azotobacter + PSB	63.235	Rs.1,44,155.40	Rs. 1,17,601.57	Rs.26,553.88	1.225
FYM 5 t ha^{-1} + P.M 2 t ha^{-1} + Azotobacter + PSB	69.007	Rs.1,51,143.40	Rs. 78,120.71	Rs.73,112.84	1.932
V.C 3 t ha^{-1} + P.M 2 t ha^{-1} + Azotobacter + PSB	65.781	Rs.1,48,318.30	Rs.89,999.43	Rs.58,318.95	1.646
SE m (±)	0.443	317.663	-	311.881	0.004
CD p=(0.05)	1.35	951.137	-	933.827	0.011

FYM= Farm yard manure, V.C= Vermicompost, P.M= Poultry manure.

(Sannagoudar *et al.,* 2024). Balancing resources and food productivity in India is a challenge and efficient intercropping is necessary for sustainability (Sharmili *et al.,* 2021). Finger millet-horsegram intercropping increased land use efficiency and weed suppression (Pradhan *et al.,* 2018). Cereal-legume intercrops, such as triticale/pea and barley/pea, enhanced grain yield and quality in low-fertility soils (Benider *et al.,* 2021). These findings highlight intercropping's role in sustainable agriculture.

CONCLUSION

Wheat + Chickpea in 3:1 row ratio along with FYM (5 t ha^{-1}), poultry manure (2 t ha^{-1}), Azotobacter and PSB, was identified as the most effective sustainable and economically viable approach for achieving higher productivity. We found that organic treatments could yield higher returns and enhance profitability, although they could have a higher cost as well, especially when intercropped. The integration of organic amendments, such as FYM and poultry manure and biofertilizers like *Azotobacter* and PSB optimized resource utilization, promoted soil health and improved nutrient cycling for higher productivity and profitability. These results further confirm the ability of organic farming systems to increase agricultural productivity while dealing with the economic problems of the farmers.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Not applicable.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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