Indian Journal of Agronomy (1st International Farming Systems Conference 2025, Special Issue) **70**: S104–S111
DOI: 10.59797/ija.v70.spl.5570

Maximizing the productivity, economic gain, and soil fertility of guava (*Psidium guajava*)-based agroforestry system

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Received: January 2025; Revised accepted: March 2025

ABSTRACT

The present study was conducted during 2023–2024 at ICAR-Central Agroforestry Research Institute, Jhansi with the objectives of evaluating the yield, yield attributes, and economics of different intercrops (barley, wheat, and chickpea) grown under guava-based agroforestry and their effects on soil physico-chemical properties in comparison with conventional sole cropping. Yield attributes of crops were recorded significantly higher under sole cropping than in guava-based agroforestry. Biological yield (9,069, 9,310, and 3,197 kg/ha) and harvest index (44.43, 44.37 and 43.93%) was also observed maximum under sole cropping than under agroforestry systems (7,578, 8,235 and 2,497 kg/ha) and (43.44, 44.09 and 40.85%) for barley, wheat and chickpea, respectively while the system productivity for guava-based agroforestry ranged between 77.80-99.72% higher over the sole cropping. Wheat equivalent yield (WEY) was recorded maximum for guava + wheat agroforestry. Guava-based agroforestry systems significantly improved soil physico-chemical properties including OC, N, P, and K availability over the sole cropping. Gross return (₹196.54 thousand/ha) as well as net return (₹154.87 thousand/ha) were found maximum for the guava + wheat-based agroforestry system. However, Guava + barley agroforestry exhibited the highest B: C ratio of 3.83 while guava + wheat agroforestry showed the maximum land equivalent ratio (1.81).

Key words: Agroforestry, Biological yield, Net returns, Productivity, Soil fertility

The Sustainable Development Goals (SDGs) of the United Nations play a crucial role in reducing global hunger malnutrition, and poverty along with the restoration of environment and ecosystem services. The burgeoning population induced different stresses in the ecosystem, which may lead to a food crisis in the future due to severe losses in production and productivity of the crops and the system because, with available land, it will be difficult to fulfill the demand for food (Ram *et al.,* 2014). Therefore, agroforestry can play a major role in curbing food security and climate change adaptation and mitigation under these situations. Indians are practicing agroforestry as a means of subsistence and a way of life because of the threats of loss of fertility, low sustainability, and soil erosion under a mono-cropping system. According to Dhyani *et al.,* (2016) and CAFRI Vision (2015 and 2020), expanding the nation's agroforestry sector can aid in addressing a few of the most significant issues brought on by climate change. In addition, it can produce a range of social, ecological, and economic advantages compared to sole-cropping. The farmers of the Bundelkhand region often face crop failure due to erratic climatic behavior (Dev *et al.*, 2020). Under such circumstances, agroforestry interventions show potential to support the livelihood of the farmers (Dev *et al.*, 2017). Farmers in this region grow low water-consuming crops like groundnut, blackgram, sesame, and millets during the *kharif* (wet) season and wheat, chickpea, barley, mustard, and lentil during the *rabi* (dry) season. Farmers inclined toward fruit-based trees in their fields can obtain additional monetary gain from fruit production.

Guava (*Psidium guajava* L.) also known as poor man's apple, is a fast-growing fruit tree species belonging to the *Myrtaceae* family and was introduced in India during the early 17th century. It is indigenous to tropical Mexico, the Caribbean, and America. L-49, a dwarf variety of guava is a hybrid known as white guava, which grows up to a height of 10 m and produces an average yield of 144 kg of

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fruits per tree. Guava is considered a hardy and high revenue-generating fruit crop even under almost neglecting conditions. India produced around 5.59 million metric tonnes of guava and the share of Uttar Pradesh in total guava production is approximately 21.28%. Guava-based agri-horticulture system is the most prominent agroforestry practiced in Uttar Pradesh.

The cereal and legume combination are the most widely used intercropping (Bybee-Finley and Ryan, 2018). Intercropping can reinforce and alleviate agroecosystems under climate change by refining resource use efficiency, improving soil water holding capacity, and enhancing the diversity and quality of habitat for beneficial insects that provide pollination services and natural pest control (Huss *et al.,* 2022). The breakdown of cereal and leguminous intercrop biomass may be the cause of the rise in the organic C content of the soil under these intercropping systems. Nath *et al.,* (2003) and Aulakh *et al.,* (2004) have reported similar results about the rise in organic C of soil as a result of intercropping techniques in mango orchards. Soil organic carbon has been reported to have improved for agroforestry plantations from 6 years (Maikhuri *et al*., 2000) to 20 years (Saha *et al*., 2011) which may increase from 0.2%-4.0% at the topsoil. Thus, under intercropping systems, the addition and recycling of biomass contributes to improved soil aeration, organic C content, and soil structure. This improvement in the physical, chemical, and biological properties of the soil may be through its increased ability to hold water (Kumar and Pandey, 2004). Continuous intercropping, according to Sharma *et al.,* (2017), increases soil fertility, reduces soil erosion, lowers the bulk density of the soil, increasing its ability to hold water by lowering the proportion of pore space. Agroforestry land usage also shows superior land equivalent ratio or comparable to mono-cropping systems, demonstrating the system's production efficiency (Peng *et al.,* 2023) and as a result, agroforestry generates more revenue for farmers per unit of land than either forestry or pure agriculture (Dagar and Tewari, 2017). The objective of this study was i) to evaluate the yield, yield attributes, and economics of different intercrops grown under guava-based agroforestry in comparison with conventional sole cropping, and ii) to assess the impact of growing different intercrops on soil physico-chemical properties in the semi-arid conditions of the Bundelkhand region.

MATERIALS AND METHODS

The experiment was conducted in an 8-year-old guava plantation block (established in 2016) during the *rabi* season of 2023–24 at the research farm of ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi, Uttar Pradesh having 78°32' E longitude, 25°50' N latitude and altitude of 272 m amsl. Jhansi is located in the semi-arid region of central India with an average rainfall of 867 mm and most of the rainfall occurs during the monsoon season. May and June are the hottest months in this region (Dev *et al.,* 2016). The mean monthly maximum temperature ranges from 17.4 °C (January) to 40.2 °C (April) whereas, the mean monthly minimum temperature ranges from 4.6 °C (January) to 21.2 °C (April) at this location. The experimental field has a loamy soil texture, intermixed black soil with initial pH, electrical conductivity, total dissolved solids, bulk density, and soil organic carbon of 7.70, 0.24 dS/m, 188.70 µg/ml, 1.29 Mg/m^3 and 0.54% under agroforestry system and 7.84, 0.32 dS/m, 205.5 µg/ml, 1.37 Mg/m^3 and 0.38% under sole cropping, respectively. Nutrient-wise, the experimental soil in the agroforestry system and sole cropping had poor available N (184.82 and 168.48 kg/ha), medium available P (11.74 and 9.77 kg/ha), and available K (238.43 and 245.86 kg/ha), respectively. The experiment evaluated different *rabi* crops including barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and chickpea (*Cicer arietinum*) under a guava (*Psidium guajava*)-based agroforestry system planted at a spacing of 10×10 m. The plot size for the each treatment was 20×10 m and a total of six treatments viz., T_1: guava + barley, T_2: sole barley, T_3: guava + wheat, T_4: sole wheat, T_5: guava + chickpea, and T_6: sole chickpea was imposed in quintuples following completely randomized block design (CRBD). A wooden rod was used to measure the height of the tree from its base to its top. The length of the rod was measured with a measuring tape and recorded in meters (m). Using a measuring tape at the collar, the girth of the guava plant was measured at a convenient height, 10–12 cm above the ground, and expressed in centimetres (cm). By placing a measuring tape horizontally beneath the tree crown at two locations beneath the majority of extending branches in both the east-west (E-W) and north-south (N-S) directions, the crown width, or spread, was measured. The average crown spread (m) was calculated using the formula:

$$CS = \frac{S_1 + S_2}{2}$$

Where CS= Crown spread, S_1 = Crown spread in N-S direction (m), S_2 = Crown spread in E-W direction (m).

After the harvest of the guava fruits, a pruning operation was carried out in May 2024 and harvested biomass was sun-dried for five days under open sunlight and weight was measured in kg/tree. The total fruits harvested per tree were weighed and expressed as fruit yield (kg/ha). For yield attributes, the length of spikes (cm) of wheat and barley was measured from the base to the tip of the spikelet and the average length was calculated. The number of grains/spike in the case of barley and wheat while the number of pods/plant and number of seeds/pod in the case of chickpea were calculated by manual counting. Grain yield (kg/ha) and straw/stover yield (kg/ha) were calculated for each plot. Biological yield (kg/ha) was calculated by adding the total grain yield and straw yield whereas the harvest index (%) was estimated by the following formula:

$$\text{HI (\%)} = \frac{\text{Economic yield (Grain yield)}}{\text{Biological yield (Grain + Straw yield)}} \times 100$$

For test weight (g), a composite sample of grains was collected from the tagged plants, harvested from each replication and 1000 grains were counted randomly and weighed using an electric balance of higher precision. The experimental site was divided into different representative points with three replications and soil samples were collected randomly from a depth of 0-15 cm using soil auger at the crop harvesting stage. The collected soil samples were brought to the laboratory using well-labeled polythene bags. These samples were shade-dried and then ground using a wooden pestle and passed through a 2.0 mm sieve to obtain uniform fine powder for analysis of various physico-chemical properties. These properties included pH, electrical conductivity (EC), total dissolved solids (TDS), bulk density, organic C, and availability of N, P, and K through standard procedures.

Wheat Equivalent Yield (₹/ha): the following formula was used to calculate the equivalent yield for barley, wheat, and chickpea, separately:

$$\text{WEY} = \frac{\text{Yield of crop A (kg/ha)} \times \text{Average price of crop A (₹)}}{\text{Average price of Wheat (₹)}}$$

Cost of Cultivation (₹/ha): The cost incurred for inputs, field operation, and management of guava was calculated on a per hectare per year basis.

Gross Return (₹/ha): The prevailing local market prices were used to convert the yield of agricultural crops and fruits into rupees/ha.

Gross returns = Average yield per hectare × Average market price per quintal (₹)

Net Return (₹/ha): Net returns were calculated by subtracting the cost of cultivation from gross returns as follows.

Net returns (₹/ha) = Gross returns (₹/ha) – cost of cultivation (₹/ha)

Benefit-Cost ratio: The B:C ratio was calculated by using the following expression:

$$\text{B: C} = \frac{\text{Net returns (₹/ha)}}{\text{Cost of cultivation (₹/ha)}}$$

Land Equivalent Ratio (LER): It was calculated as the ratio of the area needed under intercropping to the area under sole cropping using the following formula:

$$\text{LER} = \frac{\text{Yield of crops in agroforestry}}{\text{Yield of crops in sole cropping}} + \frac{\text{Yield of guava in agroforestry}}{\text{Yield of guava in sole cropping}}$$

The experimental data of various growth, yield attributes, soil, and economic parameters were subjected to analysis of variance (ANOVA). The level of significance was tested by F-test (Gomez and Gomez, 1984), and standard error of means (SEm±) and critical difference (CD) at a 5% level of significance were estimated to compare the means of each parameter. However, growth parameters (plant height, dry matter accumulation, no. of tillers of barley and wheat, primary and secondary branches, and plant population of chickpea) and yield attributes of barley, wheat, and chickpea were compared using the t-test, as these parameters of one crop are not comparable with other crops.

RESULTS AND DISCUSSION

Growth attributes of guava

Guava exhibited the average height, girth, and crown spread ranged between 4.06–4.21 m, 28.16–29.26 cm, and 5.61–6.65 m, respectively (Table 1) whereas, the total dry biomass of the pruned branches and dry leaf biomass of pruned branches ranged from 4.80-5.40 kg/plant and 1.40–1.85 kg/plant, respectively.

Yield attributes of intercrops

The data on different yield attributes of guava and intercrops were found to be the maximum in sole cropping than in the agroforestry system (Table 2). The number of grains per spike was found maximum for barley and wheat in sole cropping (44.52 and 55.52, respectively) than in their respective agroforestry system (42.46 and 52.91). Similarly, the length of the spike was also found maximum in sole barley (14.40 cm) and in sole wheat (9.92 cm) in comparison to barley (14.19) and wheat (9.46) in the agroforestry system. The number of seeds per pod for sole chickpea was found to be the maximum in sole cropping

Table 1. Guava growth attributes and dry biomass of pruned branches and leaves

Treatment	Height (m)	Girth (cm)	Crown spread (m)	Dry biomass of pruned branches (kg/tree)	Dry leaf biomass from pruned branches (kg/tree)
Guava + Barley	4.06	28.49	5.61	4.80	1.40
Guava + Wheat	4.07	29.26	5.93	5.40	1.85
Guava +Chickpea	4.21	28.16	6.65	5.10	1.75

(2.02) than in intercropping (1.84). The number of pods per plant was also recorded highest in sole cropping (52.57) and minimum in agroforestry system (47.22). Guava yield with barley, wheat, and chickpea intercropping were found to be 8800 kg/ha, 8450 kg/ha, and 8900 kg/ha, respectively. The result for grain yield for barley, wheat, and chickpea was found maximum in sole cropping i.e. 4030 kg/ha, 4131 kg/ha, and 1404 kg/ha than in agroforestry system (3292 kg/ha, 3631 kg/ha and 1020 kg/ha, respectively). The straw/stover yield for barley, wheat, and chickpea was also higher (5039 kg/ha, 5179 kg/ha, and 1792 kg/ha, respectively) in sole cropping than in agroforestry system (4286 kg/ha, 4604 kg/ha, and 1477 kg/ha, respectively).

Likewise, biological yield was also highest in sole cropping viz., 9069 kg/ha, 9310 kg/ha, and 3197 kg/ha in barley, wheat, and chickpea, respectively. The corresponding values of biological yield in these crops with guava-based agroforestry were 7578 kg/ha, 8235 kg/ha, and 2497 kg/ha, respectively. Harvest index was found to be maximum in sole barley (44.43), sole wheat (44.37), and sole chickpea (43.93) over respective agroforestry systems (43.44 for barley, 44.09 for wheat, and 40.85 for chickpea). Similar variation has also been observed in the test weight of barley, wheat, and chickpea crops.

Under guava trees, crop yield attributes *viz.,* spike length, number of grains per spike, number of pods per plant, number of seeds per pod, grain yield, straw/stover yield, biological yield, harvest index, and test weight were comparatively lower than sole cropping. Under guava, the reduction in yield attributes in the case of crops may be due to the competition for light, nutrients, and water for growth and development, and as sunlight received is comparatively greater in sole cropping, so light availability could be a reason for the reduction in yield and yield attributes of barley, wheat, and chickpea under trees. Similar observations have also been reported by Chauhan *et al.,* (2012) and Gusain (2016). Reduction in yield contributing factors *viz.,* plant height, test weight, and number of grains per spike may reduce the biological yield which also affects the harvest index (Palsaniya *et al.,* 2012; Dev *et al.,* 2016; Upadhyay *et al.,* 2021; Kalakappa *et al.,* 2022; Kombra *et al.,* 2023). Due to simultaneous competition between crops and trees for growth elements including water, nutrients, and light, which has a detrimental effect on yield-contributing characteristics, the guava-based agroforestry system saw a decrease in grain production and harvest index. Similar findings were previously reported by Tripathi *et al.,* (2006) and Sarvade *et al.,* (2014). Grain and stover yields of rabi crops under guava-based agroforestry are reduced since there is less space available (approximately 20% less area because of the perennial component).

Soil physico-chemical properties

It was observed that pH before the initiation of the experiment was 7.70 in the guava field and 7.84 in the sole crops field (Table 3). The respective values of EC, TDS, and bulk density

Table 2. Yield attributes and yield of barley, wheat, and chickpea under agroforestry system and sole cropping

Treatment	Grain per spike/ Seeds per pod	Length of spikes (cm)	Pods/ plant	Guava yield (kg/ha)	Grain yield (kg/ha)	Straw/Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)	Test weight (g)
Barley									
T_1- Guava + Barley	42.46 ± 0.35	14.19 ±0.20	-	8,800	3292±1.82	4286 ± 1.09	7578 ± 1.26	43.44 ± 0.01	42.87±0.65
T_2- Sole Barley	44.52 ± 0.86	14.40 ±0.23	-	-	4030±1.42	5039 ± 1.27	9069 ± 0.20	44.43 ± 0.01	43.17±0.39
Wheat									
T_3- Guava+ Wheat	52.91 ± 0.93	9.46 ±0.14	-	8,450	3631±1.70	4604 ± 1.10	8235 ± 2.69	44.09 ± 0.01	41.95 ±0.69
T_4- Sole Wheat	55.52 ± 0.69	9.92 ±0.12	-	-	4131±1.23	5179 ± 1.54	9310 ± 0.84	44.37 ± 0.01	44.72 ±0.20
Chickpea									
T_5- Guava+ Chickpea	1.84 ± 0.04	-	47.22± 0.88	8,900	1020±1.48	1477 ± 1.58	2497 ± 2.01	40.85 ± 0.04	267.50 ±0.64
T_6- Sole Chickpea	2.02 ± 0.08	-	52.57± 0.87	-	1404±1.25	1792 ± 1.60	3197 ± 1.67	43.93 ± 0.03	272.75 ±0.85

Table 3. Soil pH, electrical conductivity, total dissolved solids, and bulk density under sole cropping and guava-based agroforestry system

Treatment	*p*H	EC (ds/m)	TDS (µg/ml)	Bulk Density (Mg/m^3)
Initial Soil properties (October, 2023)				
Initial-Guava-based AFS	7.70	0.24	188.70	1.29
Initial-Sole cropping	7.84	0.32	205.50	1.37
Soil properties after harvesting (April 2024)				
T_1- Guava +barley	7.66±0.12^b	0.30±0.09^a	213.75±3.8^c	1.30±0.05^{bc}
T_2- Sole barley	7.80±0.08^a	0.37±0.07^a	220.51±2.5^b	1.41±0.07^a
T_3- Guava +wheat	7.55±0.02^b	0.30±0.06^a	193.25±5.2^d	1.28±0.04^d
T^4- Sole wheat	7.81±0.03^a	0.39±0.07^a	208.25±2.1^a	1.39±0.04^{ab}
T_5- Guava +chickpea	7.60±0.04^b	0.28±0.05^a	205.75±2.6^e	1.26±0.06^{cd}
T_6- Sole chickpea	7.80±0.06^a	0.33±0.07^a	244.50±3.2^d	1.35±0.03^{ab}

in the guava field and sole fields were 0.24 dS/m and 0.32 dS/m, 188.70 µg/ml and 205.50 µg/ml, and 1.29 Mg/m^3 and 1.37 Mg/m^3, respectively. After the harvesting stage, pH, EC, TDS, and bulk density were also estimated. pH values ranged from 7.55 to 7.81 and maximum pH was recorded in treatment T6 (sole chickpea), which was at par with treatments T2 and T4. The EC value ranged from 0.28-0.39 dS/m and treatment T6 registered the maximum value (0.39 dS/m), which was statistically different from other treatments.

TDS value varied from 193.25 to 244.50 µg/ml but wheat in sole cropping recorded the highest TDS (244.50 µg/ml), which was statistically different from other treatments. Bulk density among different treatments ranged from 1.26 to 1.41 Mg/m^3 and it was found to be the highest in sole barley (1.41 Mg/m^3) and it was statistically at par with treatments T4 and T6. The present study reported lower pH and EC in soil under a guava-based agroforestry system as compared to sole cropping, which might be due to the addition of organic matter to the surface soil under guava trees and due to the release of organic acid from the litter decomposition. Similar results in pH lowering under agroforestry systems in comparison to sole cropping have been observed by Dalal *et al.,* (2015), Singh *et al.,* (2018), and Kumar *et al*., (2022). In the present study, bulk density was minimal in the guava-based agroforestry system. It may be due to the addition of guava leaf litter as well as crop residue to the soil and its decomposition resulted in higher soil organic carbon content and thereby decreased the bulk density. Dalal *et al*., (2015) and Swain (2016) found similar results in the case of different agroforestry systems.

Initially, organic carbon and available N, P, K analysis was performed for agroforestry and sole cropping in which organic carbon was 0.54 % in agroforestry system and 0.38 % in sole cropping and available N, P, K was 184.82, 11.74 and 238.43 kg/ha in agroforestry while in sole cropping it was 168.48, 9.77 and 245.86 kg/ha, respectively (Table 4). After harvesting of the crops (sole and in agroforestry system), soil organic carbon ranged from 0.40-0.60 % in which T1 recorded the highest organic carbon (0.60%), while, the lowest organic carbon (0.40%) was recorded in T6. The highest available nitrogen was recorded in T3 (240.54 kg/ha), which was statistically higher than the other treatments of sole cropping and agroforestry systems. Likewise, available phosphorous was recorded maximum in T1 (14.96 kg/ha), which was at par with treatment T5 and significantly higher over

Table 4. Soil organic carbon and available NPK under sole cropping and guava-based agroforestry system

Treatments	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Initial Soil properties (October, 2023)				
Initial-Guava-based AFS	0.54	184.82	11.74	238.43
Initial-Sole cropping	0.38	168.48	9.77	245.86
Soil properties after harvesting (April 2024)				
T_1- Guava + Barley	0.60±0.02^a	204.10±8.83^b	14.96±0.64^a	241.05±8.16^a
T_2- Sole Barley	0.43±0.01^c	177.06±4.67^d	10.03±0.26^c	239.75±9.73^a
T_3- Guava + Wheat	0.58±0.02^b	240.54±11.52^b	12.523±0.6^b	244.00±3.67^a
T_4- Sole Wheat	0.45±0.01^d	191.55±6.40^e	9.387±0.31^c	240.82±10.69^a
T_5- Guava + Chickpea	0.52±0.01^a	210.11±3.86^a	14.68±0.27^a	242.87±4.71^a
T_6- Sole Chickpea	0.40±0.01^c	160.71±4.95^c	9.56±0.29^c	240.52±12.26^a

the other treatments. However, available potassium in soil did not vary significantly among the treatments.

The increased soil fertility in the agroforestry system is not the effect of a single cropping season, rather it is the cumulative effect of the agroforestry system over the years (Since 2016, the year of plantation). The agroforestry trees play an important role in nutrient cycling by adding leaf litter, fine root decomposition, and a better habitat for soil microbial fauna (Singh *et al.,* 2018). The higher organic carbon in the agroforestry system may be due to the addition of leaf litter and crop residue at the surface layer. A similar variation of SOC has been observed by Ghosh *et al.,* (2017), Singh *et al.,* (2018), and Kumar *et al.,* (2022) where maximum SOC content was found under tree + crop systems over the sole cropping. Bhavya *et al.,* (2018) and Reza *et al.,* (2014) observed that soils under the horticulture crops and forest systems showed higher amounts of SOC than the soil of annual cropping. Fahad *et al.,* (2022) reported that by stabilizing soils, encouraging aggregate formation, storing carbon in soils, enhancing the availability of nutrients, and retaining and fostering a healthy soil biota, agroforestry can restore soil heath. Similar results have also been reported by Sharma *et al.,* (2022). It was observed from the result that phosphorous availability was maximum under guava-based agroforestry as compared to sole cropping. This may be due to higher leaf litter accumulation which releases acids during the process of decomposition. Similar findings were reported by Majumdar *et al*., (2004) and Ghimire (2010).

Economic analysis of guava-based agroforestry

The results showed that wheat equivalent yield was found maximum in the guava + wheat-based agroforestry system (7345 kg/ha) (Table 5). The minimum wheat equivalent yield (3277 kg/ha) was observed in treatment T2, which was statistically at par with treatment T4. The wheat equivalent yield from the different treatments was in the order: T3 (7345 kg/ha) > T1 (6545 kg/ha) > T5 (6304 kg/ha) > T6 (4131 kg/ha) > T4 (3294 kg/ha) >T2 (3277 kg/ha). Total cost of cultivation was in the order: T3 (₹41.67 thousand/ha) > T1 (₹37.03 thousand/ha) > T5 (₹36.43 thousand/ha) > T4 (₹28.04 thousand/ha) > T2 (₹23.40 thousand/ha) > T6 (₹22.80 thousand/ha). The gross returns as well as net returns obtained from different treatments followed a similar trend. The maximum gross return was obtained in T3 (₹196.54 thousand/ha) which was statistically different from all other treatments. Whereas, treatment T6 recorded the lowest gross return (₹92.87 thousand/ha). The overall order of the gross return obtained from the different treatments was: T3 (₹196.54 thousand/ha) > T1 (₹178.91 thousand/ha) > T5 (₹158.21 thousand/ha) > T4 (₹127.65 thousand/ha) > T2 (₹109.83 thousand/ha) > T6 (₹92.87 thousand/ha).

The net return was obtained maximum in T3 (₹154.87 thousand/ha) while it was observed minimum in T6- Sole Chickpea (₹70.07 thousand/ha) and both were statistically different from all other treatments. The overall net returns in decreasing order (₹ x 10^3/ha) were: T3 (154.87) > T1 (141.89) > T5 (121.78) >T4 (99.61) > T2 (86.43) >T6 (70.07). B:C ratio among all treatments was recorded as maximum in T1 (3.83) which was statistically at par with T5 (3.71) and T2 (3.69) while minimum in T4 (3.07). B: C ratio order among different treatments was: T1 (3.83) > T5 (3.71) > T2 (3.69) > T6 (3.55) > T3 (3.34) > T4 (3.07). The maximum land equivalent ratio was observed in the guava + wheat-based agroforestry system (1.81) followed by guava + barley (1.79) and guava + chickpea (1.71).

Economic analysis showed that wheat equivalent yield was highest for the Guava + Wheat-based agroforestry system. The system productivity for guava-based agroforestry ranged between 77.80–99.72% higher over the sole cropping. Similar findings were also observed by Ghosh *et al.,* (2017) who reported that guava-based agroforestry had more system productivity than sole cropping. Gross and net returns from the guava-based agroforestry system were maximum as compared to sole cropping due to the returns from the guava fruits. Similar findings were also reported by Dwivedi *et al.,* (2007), Malik and Butola (2010), Ghosh *et al.,* (2017), and Kumar *et al.,* (2022) in the case of different agri-horticulture systems.

Table 5. Economic analysis of guava-based agroforestry system and sole cropping after harvesting

Treatment	Wheat equivalent yield (kg/ha)	Cost of cultivation ('000 ₹/ha)	Gross return ('000 ₹/ha)	Net return ('000 ₹/ha)	Benefit: cost ratio	LER
T_1- Guava+ barley	6545.39±115.90^{b}	37.03	178.91±3.94^{b}	141.89±3.94^{b}	3.83±0.10^{a}	1.79
T_2- Sole barley	3277.24±86.58^{e}	23.40	109.83±2.90^{e}	86.43±2.90^{e}	3.69±0.12^{ab}	-
T_3- Guava+wheat	7345.45±66.76^{a}	41.67	196.54±3.31^{a}	154.87±3.31^{a}	3.34±0.09^{bc}	1.81
T_4- Sole wheat	3294.21±110.15^{e}	28.03	127.65±3.11^{d}	99.61±3.11^{d}	3.07±0.13^{c}	-
T_5- Guava +Chickpea	6304.98±114.61^{c}	36.43	158.21±2.07^{c}	121.78±2.07^{c}	3.71±0.05^{a}	1.71
T_6- Sole chickpea	4131.02±127.33^{d}	22.80	92.87±3.93^{f}	70.07±3.93^{f}	3.55±0.14^{b}	-

The highest B:C ratio was found in the guava-based agroforestry system with all studied intercrops rather than the respective sole cropping. Similarly, the highest B:C ratio from the agroforestry system was also reported by Swain (2014), Rani *et al.,* (2016), and Rathore *et al.,* (2022). As the B:C ratio can't predict accurately the benefits of the agroforestry system hence, net returns were considered to suggest the profitable system and it was found that the Guava + Wheat-based agroforestry system is more advantageous as compared to other agroforestry systems. Similarly, studies conducted in tropical regions have suggested that agroforestry systems can generate higher profits compared to mono-cropping due to the diversification of income sources (Garrity *et al.,* 2010). Also, the intercropping of trees and crops in agroforestry systems diversifies farmers' income sources by expanding their product range (Nair, 2018). All tree-crop combinations *i.e.* guava+ barley, guava + wheat, and guava + chickpea are advantageous as the LER value for these agroforestry systems was more than 1. Indeed, an LER of more than 1 denotes that intercropping in agroforestry is advantageous as suggested by Pent (2020).

Thus, the study concluded that the guava-based agroforestry systems (guava + barley, guava + wheat, and guava + chickpea) are more productive and profitable as compared to sole cropping of barley, wheat, and chickpea. Among three guava + crop combinations, guava + wheat can be recommended for harvesting the maximum benefits in the Bundelkhand region of India.

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