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Growth Behavior and Productivity of Intercrops under *Gmelina arborea* Based Agroforestry Systems

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Authors' contributions

This work was carried out in collaboration among all authors. Author RPD contributed to the conceptualization, methodology, investigation and writing of the original draft. Authors RB and VS provided supervision and resources. Authors SBD and YS handled supervision and funding acquisition. Authors AKS and KK were involved in reviewing, editing and assisting with research paper development. Author PC contributed to field data collection and research paper development assistance. All authors read and approved the final manuscript.

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ABSTRACT

Agroforestry and intercropping systems offer sustainable alternatives to monoculture, enhancing yield stability and ecosystem services. This study investigated the growth behavior and productivity of three intercrops – *Cajanus cajan* (Arhar), *Vigna unguiculata* (Cowpea), and *Brassica juncea* (Mustard) – within a *Gmelina arborea*-based agroforestry system compared to their sole cropping counterparts. The field experiment was conducted over two consecutive years (2019-20 and 2020-21) at the Forestry Research Farm, JNKVV, Jabalpur, using a Complete Randomized Block Design with seven treatments (three intercropping combinations, sole *Gmelina*, and three sole crops) replicated three times. Data were collected on plant population, height, branches per plant, pods/siliques per plant, grains per pod/silique, and grain, straw, and biological yields. Results indicated that sole cropping treatments generally maintained higher plant populations per meter row compared to intercropping under *Gmelina*. However, growth parameters varied significantly; *Gmelina* with Arhar (T1) consistently recorded the highest crop height, branches per plant, and total pods per plant across both years and in pooled data, significantly outperforming most other treatments in pod production. *Gmelina* with Mustard (T3) exhibited high potential, particularly in grain and biological yield, especially in the first year. While sole Arhar (T5) also performed well, particularly for yield components, intercropping combinations demonstrated viable productivity. A general decline in intercrop performance was observed in the second year when *Gmelina* trees were older. The findings suggest that *Gmelina*-based agroforestry systems can support diverse crop production, with specific combinations like *Gmelina*-Arhar and *Gmelina*-Mustard showing promise, although tree presence influences crop density and yield dynamics over time.

Keywords: Land used systems; intercropping; equivalent yield; harvest index; Arhar; etc.

ABBREVIATIONS

Gmelina arborea	:	*G. arborea*
Cajanus Cajan	:	*Arhar*
Vigna Unguiculata	:	*Cowpea*
Brassica Juncea	:	*Mustard*

1. INTRODUCTION

Agroforestry refers to fields that have a significant amount of trees, bushes, and/or hedges. It exists in every agricultural climate region. It plays a crucial role in the sub-humid tropical zones. In contrast to the semi-arid regions, there is an abundance of seasonal rainfall that can be utilized by deep-rooted trees, which would otherwise go to waste. Additionally, during dry seasons, deep roots and trees are essential for providing permanent vegetation is vital for the conservation of soil and water at the beginning of the rainy period. Intercropping under trees farming typically involves with other crops and occasionally animals. It is profitable and good for the environment and people. There are numerous forms and approaches to agroforestry in the tropics for growing fruit trees, nuts, and other crops in varied forest gardens, having animals graze partially under trees (silvo-pastoralism) and growing trees alongside crops are some typical agroforestry techniques.

Intercropping, which involves growing two or more crops together either at the same time or in a relay fashion, along with agroforestry, which integrates trees into at least 10% of farmland, offers an alternative farming method with numerous benefits compared to industrial monoculture. Examples from these approaches illustrate how growing multiple crops can lead to higher yields, enhanced stability, improved ecosystem services, and social advantages when implemented. Additionally, we examine cases where multiple cropping systems might not be well-suited or where the expected benefits fail to materialize (Burgess et al., 2022; Assuero & Tognetti 2010). Moreover, some studies revealed that under intercropping with a sound spacing, orientation and age of trees have not effect on the productivity of cropping crops (Van Hung et al*.,* 2025 and Singh et al*.,* 2024).

Gmelina arborea, a fast-growing, multipurpose tree from the Lamiaceae family that thrives in agroforestry systems in areas like India without needing extra water or nutrients and benefits from annual pre-monsoon pruning to enhance growth based on environmental conditions, provides biomass, sequesters carbon, and supports diverse resource use.

Cajanus cajan (Arhar) cultivated throughout the world, and nearly half of pulse production occurs in Asia and maximum part of india. This crop has valuable for intercropping system due to perennial nature and highly economical value. This is the one of the important pulses crop for human diet providing all nutritional and physiological beneficial effects on health of human. There nutritional value have significantly abundance in protein, carbohydrates, and dietary fiber, and a rich source of bioactive components. Intercrops as a *Vigna unguiculata* (Cowpea) is a crop that grows well in warm seasons and is suited to tropical climates. This plant can grow in various types of soil, but it thrives best in soils that drain well. Cowpeas mature fairly quickly, which makes it possible to grow them twice a year in regions where other crops are also cultivated, as they can handle some shade. Oil seed demand in India more with population rise so the fulfillment of oil through oil seeds crops production, In this scenario, one of the best options to produce *Brassica juncea* (Mustard) is as an intercrop in agroforestry (Shah et al., 2022).Mustard crops sound yield attributes, grain, straw and biological yield of mustard but decline with respect to trees age based cropping system (Banerjee and Dhara 2011) This studies focus in growth behavior and production of intercrops of *Cajanus cajan* (Arhar), *Vigna unguiculata* (Cowpea) and *Brassica juncea* (Mustard) under *Gmelina arborea* based agroforestry system.

2. MATERIALS AND METHODS

The experimental field located in New Dusty acre area that is comes under Forestry research farm, College of agriculture, JNKVV, Jabalpur. This study done under tree (*Gmelina arborea*) component with intercrops (*i.e.* Arhar, Cowpea and Mustard) showing in two progressive year of 2019-20 and 2020-21. This studies carried out with 7 treatment combinations (*i.e.* T_1- *Gmelina*-Arhar, T_2 -*Gmelina*- cowpea, T_3-*Gmelina*-mustard, T_4- sole *Gmelina*, T_5-sole arhar, T_6-Sole cowpea, T_7- sole mustard) and this combination was replicated by 3 time. The data analysis done by CRBD (Complete randomized block design). The tree to tree spacing 2.5 m and row to row spacing 8 m are used for experimentation.

The observation of data on intercrops includes details about the number of plants, the height of the plants, the pods each plant produces, the branches per plant, the grains found in each pod or silique, the yields of grain and straw, the harvest index, and the equivalent yield of Arhar. There are following methods using to take these observation that is explain in bullets.

- The plant count was determined by tallying the number of plants within a quadrate covering 1 m² (1 m x 1 m) just prior to harvesting. Three random quadrates were selected in each plot for this purpose. The height of five randomly chosen plants in each plot was measured from the soil level to the top bud using a graduated scale in centimeters at 30 and 60 days after sowing (DAS) and again at harvest.
- For the number of branches per plant, the number of branches emerging from the main stem of five randomly chosen plants per plot was recorded at 30 and 60 DAS, as well as at harvest time.
- In terms of pods per plant, the total number of pods from five randomly selected plants per plot was counted at 30 DAS, 60 DAS, and at the time of harvest, and an average was then calculated.
- To find grains per pod, the total grains in five sample plants were counted and then divided by the total number of pods from those same plants in each plot.
- For the grain yield, after winnowing and cleaning the grains from each net plot, the total weight was measured on an electric scale. The yield for one hectare was calculated by multiplying the net plot yield by a converting factor and expressed in quintals per hectare.
- The straw yield for each plot was calculated by weighing the dried straw using a spring balance. The obtained weights were then converted into straw yield per hectare by multiplying with the appropriate factor and reported in quintals per hectare.
- The harvest index was calculated by dividing grain yield by biological yield obtained for each treatment and multiplied by 100. It is expressed in per cent and the formula is as follows:
$$\text{Harvest index (\%)} = \frac{\text{Economic yield (grain yield)}}{\text{Biological yield (plant biomass)}} X\ 100$$
- Arhar equivalent yield often used to compare different cropping systems or intercropping combinations (Cowpea and Mustard), converts yields of different crops into a common unit, typically based on market prices, using the formula:
$$\text{Arhar equivalent yield} = \frac{\text{Yield of Intercrop} * \text{Price of Intercrop}}{\text{Price of Main Crop(Arhar)}}$$

2.1 Ethical Consideration

This article does not contain any studies with human or animal subjects. The current experimental research and field study, including the collection of plant material, comply with relevant institutional, national, and international guidelines and legislation and are used for research and development.

3. RESULTS AND DISCUSSION

3.1 Plant Population (m/row length) of Crops under Different Land Use System

The data presented in Table 1 Plant population revealed that the significantly in first year, second year and pooled mean data and sole intercropping have more plant population as compare to tree intercropping. At first year data varies 24.67 to 53.67 m/row length, whereas T_6 - Sole cowpea (59.00 m per row length) found maximum plant population to T_1 - *Gmelina* with Arhar (25.00 m per row length). At second year data lies between 17.33 to 55.33 m/row length as similar as trends varies in pooled mean 21.17 to 57.17 m/row length. While the treatments T_1 (25, 17.33 and 21.17 m/row length) at par with T_5 (24.67, 21.67 and 23.17 m/row length), T_2 (52.67, 46.67 and 21.17 m/row length) at par with T_6 (59.00, 55.33 and 57.17 m/row length) and T_3 (40.33, 38.33 and 39.30 m/row length) at par with T_7 (42.67, 39.00 and 40.83 m/row length) in both year and pooled mean data respectively. The most likely reason for this that in an open environment, more light is accessible to the crop resulting in a batter rate of photosynthesis, cell multiplication and eventually a larger yield and also similar finding obtained by Puri et al., (2001), The plant population per meter row length of chickpea increased as the distance from the tree line increased similar findings were recorded by Tripathi et al. (2006), Singh et al. (2012) and Sarvade et al. (2014).

3.2 Crop Height (cm) under Different Land Use System

The Y_1 when the *Gmelina* was 4 year old the crop height varied at harvest. *Gmelina* with arhar (T_1) registered the maximum value whereas sole cowpea (T_6) registered the lowest value. In Y_2 of experimentation similar trend of crop height growth was observed. However, the height of plants grown as intercrop was reduced to some extent in comparison to the previous year. *Gmelina* with Arhar (T_1) accounted highest value and Sole Cowpea (T_6) secured lowest value. The pooled values of crops height of both the year witnessed significant variation at harvest. *Gmelina* with Arhar (T_1) significantly superior to all treatments except sole Arhar (T_5) these was found partly. Dhyani et al. (2009) reported that crop height of intercrops effected by their genetical character and soil productivity as well as the age of agroforestry system. The finding are augmented with Bhusara et al. (2018) and Sharma et al. (2023).

3.3 Branch Plant^{-1} (Number) of Crops

The details regarding the quantity of branches per plant in the various intercrops can be found in Table 3 and Fig. 1. There is a notable difference in the number of branches observed during the first (Y_1) and second year (Y_2) of the experiment across the crop seasons. In Y_1, when the trees had reached 4 years of age, the quantity of branches per plant varied at the time of harvesting. The average values across treatments ranged from 3. 87 to 20. 40, with *Gmelina* with Arhar (T_1) showing the highest value, while cowpea grown alone (T_6) recorded the lowest. In Y_2, when the trees were 5 years old, there was a decrease in branches per plant

Table 1. Plant population (m/row length) of crops under different land use system

Treatments	2019-20(Y_1)	2020-21(Y_2)	Pooled Mean
T_1(*Gmelina* Arhar)	25.00	17.33	21.17
T_2 (*Gmelina* -Cowpea)	52.67	46.67	49.67
T_3 (*Gmelina* - mustard)	40.33	38.33	39.33
T_4 (Sole *Gmelina*)	-	-	-
T_5 (Sole Arhar)	24.67	21.67	23.17
T_6 (Sole Cowpea)	59.00	55.33	57.17
T_7 (Sole mustard)	42.67	39.00	40.83
Sem±	1.68	1.97	1.84
CD=	7.14	8.37	6.51

Table 2. Crop height (cm) under different land use system at harvest stages

Treatments	2019-20 (Y_1)	2020-21 (Y_2)	Pooled Mean
T_1 (*Gmelina* -Arhar)	156.00	153.33	154.67
T_2 (*Gmelina* -Cowpea)	135.67	131.67	133.67
T_3 (*Gmelina* - mustard)	132.33	129.00	130.67
T_4 (Sole *Gmelina*)	-	-	-
T_5 (Sole Arhar)	143.00	140.67	141.83
T_6 (Sole Cowpea)	115.33	109.67	112.50
T_7 (Sole mustard)	130.33	124.33	127.33
Sem±	2.89	3.80	3.38
CD=	12.26	16.10	11.98

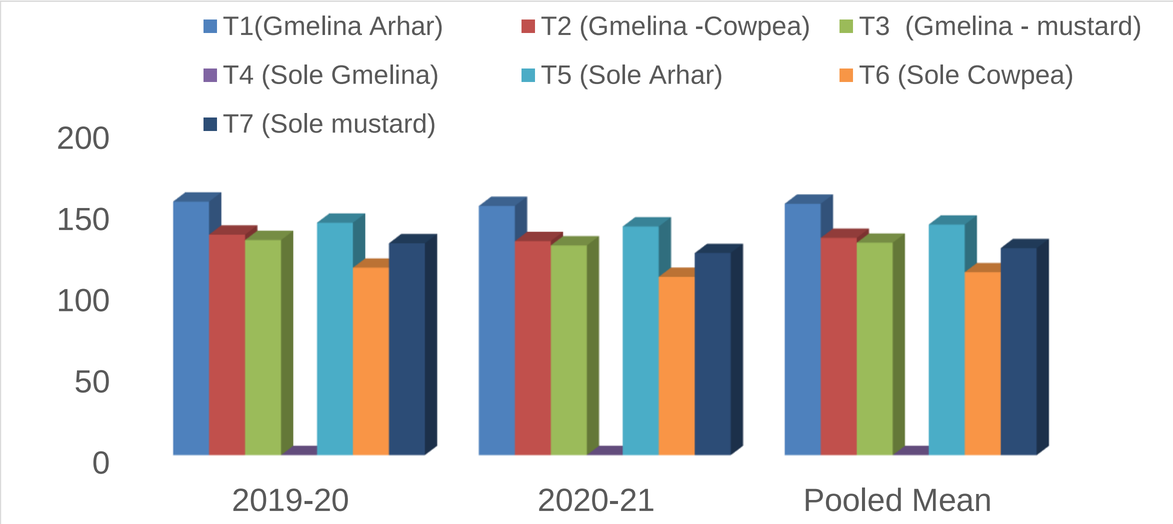

Fig. 1. Crop height (cm) under different land use system at harvest stages

compared to Y_1, with variations also noted at harvest time. The average values from the treatments ranged from 3. 40 to 20. 13, where *Gmelina* with Arhar (T_1) again demonstrated a significantly higher value, and cowpea grown alone (T_6) had the lowest numbers. In the combined average data for branches per plant, a similar pattern emerged, with values ranging from 3. 63 to 20. 27. Moreover, *Gmelina* with Arhar (T_1) and sole Arhar (T_5) showed significantly higher numbers compared to all other treatments. The branching of intercrops have genetical characters of individual reported by Yang et al., 2022. Moreover, the significant variation shown in open and tree based system due to environmental and lodging effect on the intercrops reported by Shah et al., 2022.

3.4 Pod/Silique Branch^{-1} (Number) of Crops

Reviewing data in Table 3 and Fig. 2 shows that the number of pods or siliques per plant in the crops changed significantly under various treatments during both years of the study. In the first year, the numbers ranged from 67. 09 to 427. 15 during the trials. Treatments like *Gmelina* with Arhar (T_1), *Gmelina* with mustard (T_3), and sole Arhar (T_5) had significantly higher values compared to other treatments. However, in the second year, the values decreased compared to the first year, ranging from 47. 61 to 402. 13. The trend in values remained similar, with *Gmelina* with Arhar (T_1) having the highest values, followed by sole Arhar (T_5) and then *Gmelina* with mustard (T_3). T1 showed clear superiority over both T_3 and T_5. In many cases, *Gmelina* with Arhar (T_1) was significantly better than all other treatments, showing a trend of values as follows: $T_1 > T_5 > T_3 > T_2 > T_7 > T_6$. this difference may be attributed to a higher incidence of insect pests encountered in the second year of the trial. Similar findings on pod or silique yield and productivity were reported by Daamen et al. (1994) and Manosathiyadevan et al. (2017).

Table 3. Number of branch plant^{-1}, Number of pod/silique branch^{-1} and Total Number of pod/silique Plant^{-1} of crops under different land use system

Parameters	Number of branch plant^{-1}			Number of pod/silique branch^{-1}			Total number of pod/silique plant^{-1}		
Treatments	**2019-20(Y_1)**	**2020-21(Y_2)**	**Pooled Mean**	**2019-20(Y_1)**	**2020-21(Y_2)**	**Pooled Mean**	**2019-20(Y_1)**	**2020-21(Y_2)**	**Pooled Mean**
T_1(*Gmelina* Arhar)	20.40	20.13	20.27	18.67	20.33	19.50	427.15	402.13	414.64
T_2 (*Gmelina* -Cowpea)	5.00	4.83	4.92	27.80	24.00	25.90	136.67	116.63	126.65
T_3 (*Gmelina* - mustard)	5.57	4.67	5.12	37.40	35.33	36.37	206.46	158.73	182.60
T_4 (Sole *Gmelina*)	-	-	-	-	-	-	-	-	-
T_5 (Sole Arhar)	18.33	17.17	17.75	18.67	16.83	17.75	350.15	284.73	317.44
T_6 (Sole Cowpea)	3.87	3.40	3.63	16.80	13.93	15.37	67.09	47.61	57.35
T_7 (Sole mustard)	5.80	5.00	5.40	19.13	18.33	18.73	112.29	91.69	101.99
Sem±	0.75	0.70	0.78	1.10	1.82	1.61	27.10	14.87	25.39
CD=	3.18	2.95	2.75	4.67	7.72	5.71	114.81	63.01	90.06

3.5 Pod/Silique Plant^{-1} (Number) of Crops

The analysis of data in Table 3 and Fig. 2 reveals that the number of pods or siliques produced per plant for various crops changed notably across different treatments in both experimental years. In the first year, the recorded values ranged from 67. 09 to 427. 15. The combinations of *Gmelina* with Arhar (T_1), *Gmelina* with mustard (T_3), and sole arhar (T_5) were significantly better than the other options. Additionally, T_1 outperformed T_3 while showing comparable results to T_5. In the second year, the numbers were lower than in the first year, falling between 47. 61 and 402. 13. The trend continued with *Gmelina* combined with Arhar (T_1) showing the highest values, followed by sole arhar (T_5) and then *Gmelina* with mustard (T_3). T_1 was also significantly better than both T3 and T5. When considering the pooled mean data, the range was from 57. 35 to 414. 64. The treatment involving *Gmelina* with Arhar (T_1) showed a significant superiority over all other treatments, following the trend of values as follows: $T_1 > T_5 > T_3 > T_2 > T_7 > T_6$. *pod/silique plant* $^{-1}$ mainly depends on the branch plant^{-1} and pod/silique branch^{-1} (Number) of crops reported by Shah et al., 2022.

3.6 Number of Grain pod^{-1}/Silique^{-1} of Crops

The data present in Table 4 and Fig. 3 that significantly variation found in crops over the both year and pooled means. Number of grain pod^{-1}/silique^{-1} treatment *Gmelina* T_3 significantly higher to all treatments followed by *Gmelina* with cowpea - T_2 shows maximum in 1st year, 2nd year as well as pooled mean data respectively. Moreover, Sole cowpea- T_6 (8.87, 5.00 and 6.93) and sole mustard - T_7 (9.33, 5.03 and 7.18) were found partly correlated in both year and pooled mean. However, treatments Sole Arhar -T_5 (3.90, 3.40 and 3.65) at par with *Gmelina* with Arhar- T_1 (3.73, 3.63 and 3.68) in both year and pooled mean data respectively. Number of grain pod-1/silique-1 of crops are genetic charterer of individual crops. The findings are in line with the reports of Chen et al*.* (2011) and Zhu et al*.* (2020).

3.7 Biological yield, Grain yield and Straw yield of Crops

The data pertaining in Table 5 and Fig. 4 *i.e.* Biological yield, grain yield, and straw yield in term of kg ha^{-1} this data as based on per plot yield that was multiplied with factor.

Biological yield of crops data in Y_1 found *Gmelina* with mustard-T_3 (44.44 q ha^{-1}) and *Gmelina* with arhar -T_1 (35.83 q ha^{-1}) were significantly superior to *Gmelina* with Cowpea-T_2 (29.17 q ha^{-1}) sole arhar- T_5 (28.22 q ha^{-1}), sole cowpea- T_6 (24.89 q ha^{-1}) and sole mustard- T_7 (28.83 q ha^{-1}) whereas T_2 and T_7 significantly to T_6 and T_5. Moreover the T_5 was at par with T_6. The data in Y_2 found under different treatments significantly the value of biological yield estimated in all treatments are maximum to minimum T_1 (30.72 q ha^{-1}) >T_2 (25.67 q ha^{-1}) >T_5 (25.11 q ha^{-1}) >T_6 (22.00 q ha^{-1}) >T_3 (21.00 q ha^{-1}) >T_7 (15.56 q ha^{-1}). In the pooled mean data have slightly change in yield sequence that is maximum to minimum T_1 (33.28 q ha^{-1}) >T_3 (32.72 q ha^{-1}) >T_2 (27.42 q ha^{-1}) >T_5 (26.67 q ha^{-1}) >T_6 (23.44 q ha^{-1}) >T_7 (22.19 q ha^{-1}).

Grain yield of crops in first year (2019-20) was estimated in maximum under *Gmelina* with mustard (T_3) value was 8.13, 6.06 and 7.09 q ha^{-1} and minimum found sole cowpea (T_6) values. *Gmelina* with mustard (T_3) significantly superior to *Gmelina* with arhar -T_1 (5.91, 4.27 and 5.09 q ha^{-1}) and sole cowpea –T_6 (4.61, 3.27 and 3.94 q ha^{-1}) , partly with *Gmelina* with cowpea –T_2 (6.94, 4.61 and 5.78 q ha^{-1}), sole arhar –T_5 (7.33, 5.67 and 6.50 q ha^{-1}) and sole mustard – T_7 (6.44, 5.11 and 5.78 q ha^{-1}) respectively manner in 2021-22, and 2022-23 and pooled data.

Table 4. Number of grain pod^{-1}/silique^{-1} crops under different land use system

Treatments	2019-20(Y_1)	2020-21(Y_2)	Pooled Mean
T_1 (*Gmelina* - Arhar)	3.73	3.63	3.68
T_2 (*Gmelina* -Cowpea)	10.33	9.17	9.75
T_3 (*Gmelina* - mustard)	11.97	9.93	10.95
T_4 (Sole *Gmelina*)	-	-	-
T_5 (Sole Arhar)	3.90	3.40	3.65
T_6 (Sole Cowpea)	8.87	5.00	6.93
T_7 (Sole mustard)	9.33	5.03	7.18
Sem±	0.24	0.27	0.25
CD=	1.01	1.13	0.88

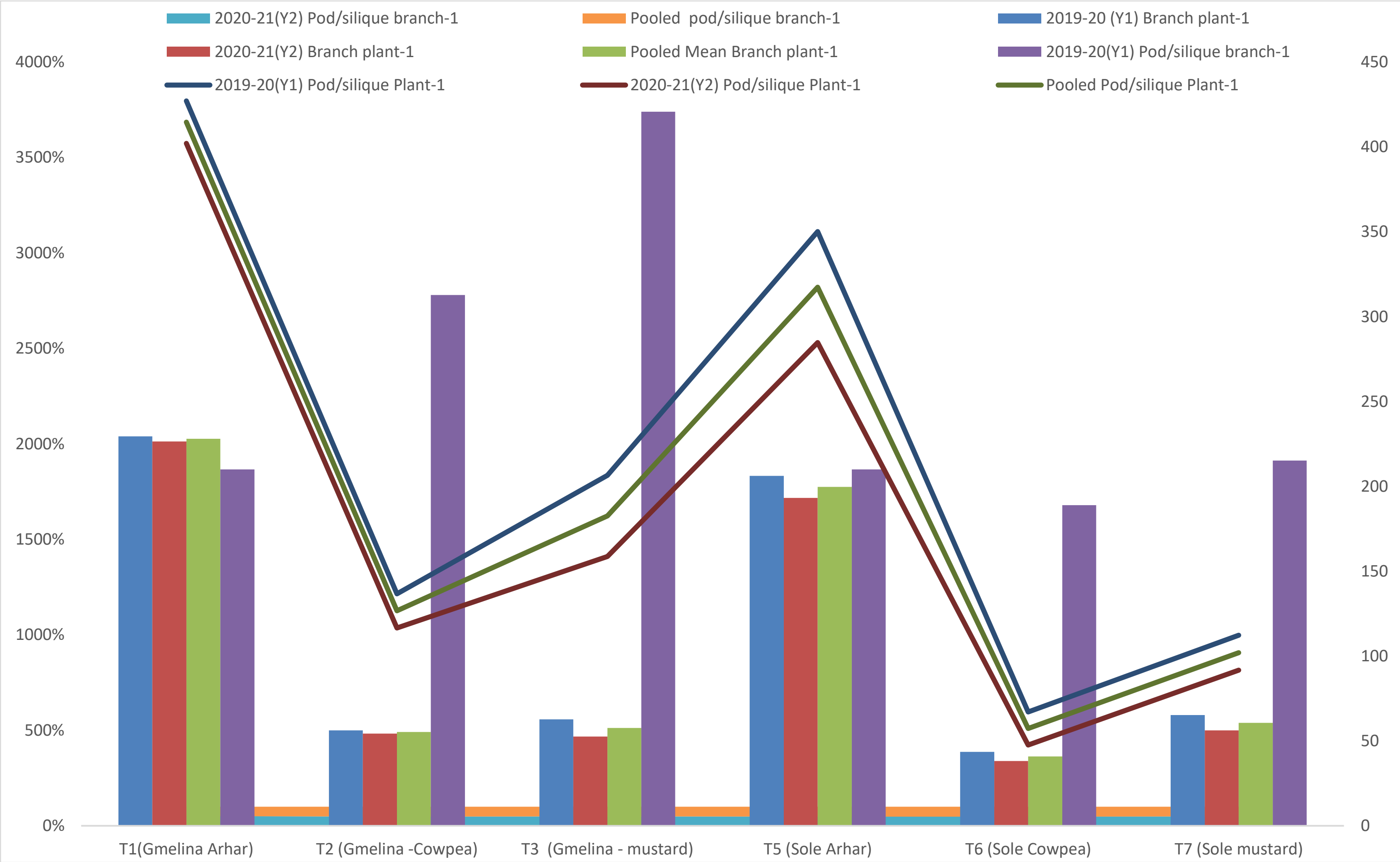

Fig. 2. Number of branch plant^{-1}, Number of pod/silique branch^{-1} of crops under different land use system

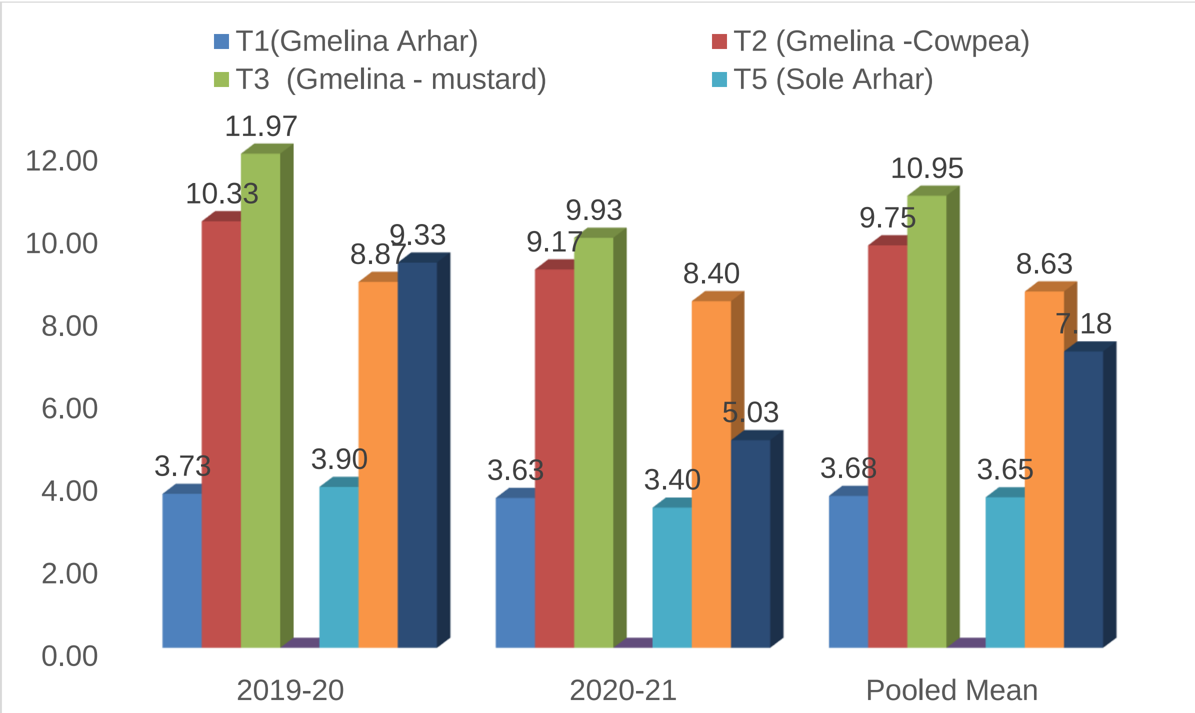

Fig. 3. Number of grain pod^{-1}/silique^{-1} crops under different land use system

Straw yield of crops in Y_1 the treatment *Gmelina* with mustard -T_3 (36.31 kg ha^{-1}) and *Gmelina* with arhar –T_1 (29.92 q ha^{-1}) were found significantly superior to treatments, whereas, the T_3 was significantly maximum to T_1. Moreover, the treatment sole cowpea- T_6 (20.28 q ha^{-1}), *Gmelina* with cowpea-T_2 (22.22 q ha^{-1}), sole arhar –T_5 (20.89 q ha^{-1}) and sole mustard – T_7 (22.39 q ha^{-1}) reflected as a partly. Straw yield in Y_2 the treatment shows trend maximum to minimum in sequence of *Gmelina* with arhar – T_1 (26.45 q ha^{-1}) > *Gmelina* with cowpea- T_2 (21.06 q ha^{-1}) > sole arhar –T_5 (19.44 q ha^{-1}) followed by sole cowpea -T_6 (18.73 q ha^{-1}) > *Gmelina* with mustard -T_3 (14.94 q ha^{-1}) > sole mustard – T_7 (10.44 q ha^{-1}). Pooled mean data sequences of higher to lower shows that *Gmelina* with arhar –T_1 (28.19 q ha^{-1}) > *Gmelina* with mustard -T_3 (25.63 q ha^{-1}) > *Gmelina* with cowpea- T_2 (21.64 q ha^{-1}) > sole arhar –T_5 (20.17 q ha^{-1}) > sole cowpea -T_6 (19.51 q ha^{-1}) > sole mustard – T_7 (16.42 q ha^{-1}).

Intercropping performs well in producing a diverse set of crop products and performs almost similar to the most productive component sole crop to produce raw products, while improving crop resilience, enhancing ecosystem services, and improving nutrient use efficiency reported by Li et al*.*, (2023) similarly results found in another researcher Rusinamhodzi, et al*.*, (2012) and Li et al*.*, (2020). Fu et al*.*, 2023 reported that strengthen leaf functional traits promote dry matter accumulation, maize-soybean relay intercropping obtained a win–win yield advantage, and maize-peanut strip intercropping achieved a trade-off yield advantage.

3.8 Harvest Index (%) of Different Agricultural Crops

The perusal of harvest index data Table 6. The harvest index data on 2019-20 (Y_1) treatment *Gmelina* with Cowpea -T_2 (23.72%), Sole Arhar-T_5 (26.02%), and Sole Mustard- T_7 (22.38%) were significantly to *Gmelina* with Arhar-T_1 (16.48%), *Gmelina* with mustard-T_3 (18.30%) and Sole cowpea-T_6 (18.29%), whereas T_7 at par with T_2 and T_5. The data trend in second year (2020-21) slightly changes to previous year the treatment *Gmelina* with mustard-T_3 (29.70%) and Sole Mustard-T_7 (33.46%) were estimated significantly superior to *Gmelina* with Arhar-T_1 (13.91%), *Gmelina* with Cowpea-T_2 (18.19%), Sole Arhar-T_5 (23.00%) and Sole cowpea-T_6 (15.04%), whereas T_3 at par with T_7. The two year mean data under different treatment found significantly the data varies form 27.92% to 15.20%, whereas the treatment *Gmelina* with mustard-T_3, Sole Arhar-T_5 and Sole Mustard- T_7 were found significantly to other treatments *i.e.*

Table 5. Biological yield, Grain yield and Straw yield of agricultural crops

Parameter	Biological yield (q ha^{-1})			Grain yield (q ha^{-1})			Straw yield (q ha^{-1})		
Treatments/Years	**2019-20(Y_1)**	**2020-21(Y_2)**	**Pooled Mean**	**2019-20(Y_1)**	**2020-21(Y_2)**	**Pooled Mean**	**2019-20(Y_1)**	**2020-21(Y_2)**	**Pooled Mean**
T_1(*Gmelina* -Arhar)	35.83	30.72	33.28	5.91	4.27	5.09	29.92	26.45	28.19
T_2 (*Gmelina* -Cowpea)	29.17	25.67	27.42	6.94	4.61	5.78	22.22	21.06	21.64
T_3 (*Gmelina* - mustard)	44.44	21.00	32.72	8.13	6.06	7.09	36.31	14.94	25.63
T_4 (Sole *Gmelina*)	-	-	-	-	-	-	-	-	-
T_5 (Sole Arhar)	28.22	25.11	26.67	7.33	5.67	6.50	20.89	19.44	20.17
T_6 (Sole Cowpea)	24.89	22.00	23.44	4.61	3.27	3.94	20.28	18.73	19.51
T_7 (Sole mustard)	28.83	15.56	22.19	6.44	5.11	5.78	22.39	10.44	16.42
Sem±	0.84	0.86	0.83	0.40	0.36	0.38	0.69	1.04	0.87
CD=	3.58	3.65	2.95	1.72	1.54	1.35	2.93	4.41	3.09

Table 6. Harvest index (%) and Arhar equivalent yield of different cropping system

Treatment/ Year	Harvest index			Arhar Equivalent yield		
	2019-20 (Y_1)	**2020-21 (Y_2)**	**Pooled Mean**	**2019-20 (Y_1)**	**2020-21 (Y_2)**	**Pooled Mean**
T_1(*Gmelina* Arhar)	16.48	13.91	15.20	3.55	2.56	3.06
T_2 (*Gmelina* -Cowpea)	23.72	18.19	20.96	2.87	2.08	2.47
T_3 (*Gmelina* - mustard)	18.30	29.70	24.00	3.72	2.82	3.27
T_4 (Sole *Gmelina*)	-	-	-	-	-	-
T_5 (Sole Arhar)	26.02	23.00	24.51	4.40	3.40	3.90
T_6 (Sole Cowpea)	18.29	15.04	16.67	1.91	1.47	1.69
T_7 (Sole mustard)	22.38	33.46	27.92	2.95	2.38	2.66
Sem±	1.13	2.27	1.79	0.20	0.17	0.18
CD=	4.77	9.61	6.33	0.84	0.72	0.65

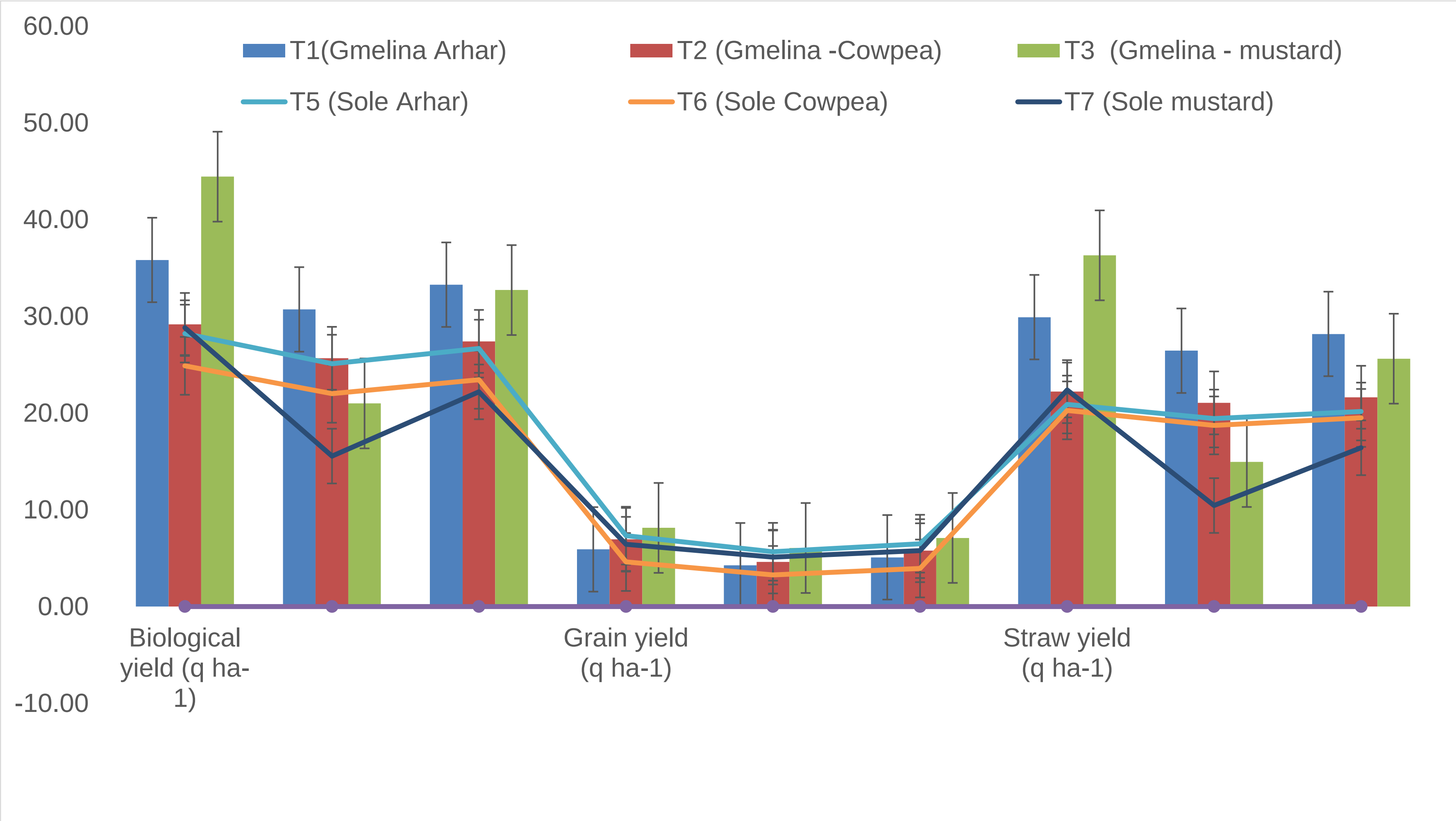

Fig. 4. Biological yield, Grain yield and Straw yield of agricultural crops

Gmelina with Arhar-T_1, *Gmelina* with Cowpea -T_2 and Sole cowpea-T_6. However, treatment *Gmelina* with mustard-T_3, Sole Arhar-T_5 and Sole Mustard-T_7 were shows partly. Porter and Semonob (2005) noted that when temperatures exceed optimal levels during flowering, it can lead to a reduction in seed production, causing limitations in the sink and a lower harvest index. Elevated temperatures in the growing season may have hindered the efficiency of nutrient movement, leading to a diminished harvest index. Suwa et al. (2010) also discussed the poor relationship between source and sink due to temperature effects. Porker et al. (2020) reported that harvest index (HI) is defined as the proportion of grain to the total dry matter of the plant and serves as an indicator of reproductive success. The determination of HI involves the interaction among genotypes (G), environment (E), and crop management (M).

3.9 Arhar Equivalent Yield (AEY)

The perusal of data Table 6 indicated that the arhar equivalent yield of crops varied significantly under different treatments in the both years of experimentation. In the 2019-20 (Y_1) of study it was observed that arhar in open (T_5) condition exhibited highest quantity (4.40 q ha^{-1}) and cowpea in open (T_6) registered the lowest quantity (1.91 q ha^{-1}). In 2020-21 (Y_2) of experimentation similar finding was obtained but the values in all treatment were marginally lesser than their corresponding values of previous year. It ranged from 3.40 to 1.47 q ha^{-1}. In the pooled analysis of data of both the year, an appreciable variation was also noticed. The ranged from 1.69 to 3.90 q ha^{-1}. The arhar equivalent yield trend was $T_5 > T_3 > T_1 > T_7 > T_2 > T_6$. Higher pigeon pea equivalent yield (1650 kg ha^{-1}) was obtained in narrow planting geometry of sole pigeon pea due to higher seed yield reported by Lavanya and Kurhade (2018). The similar trends of results are found in pigeon pea based intercropping system by Rathod et al*.,* (1990).

4. CONCLUSION

Based on the findings from the two-year field experiment study concludes that integrating *Cajanus cajan* (Arhar), *Vigna unguiculata* (Cowpea), and *Brassica juncea* (Mustard) into *a Gmelina arborea* based agroforestry system significantly modulates their growth and yield parameters compared to sole cropping systems. While the presence of *G. arborea* generally led to a reduction in plant population density for all intercrops, the performance regarding other morpho-physiological and yield attributes varied distinctly among the crop combinations. The *Gmelina*-Arhar (T1) combination consistently demonstrated robust performance, exhibiting superior plant height, branch production, and notably higher pod yield per plant, often significantly exceeding other treatments, including sole Arhar (T5) in certain aspects, indicating a strong compatibility. Furthermore, the *Gmelina*-Mustard (T3) system showed significant potential, particularly achieving high grain and biological yields, especially during the initial year of the study when the trees were younger. Therefore, while *G. arborea* agroforestry systems can support the cultivation of these important pulse and oilseed crops, the selection of appropriate intercrops is crucial. *C. cajan* appears highly suitable, and *B. juncea* shows promise, whereas *V. unguiculata* was less productive under the studied conditions. Management strategies must consider the dynamic tree-crop interactions and the impact of increasing tree age on understory crop performance to optimize overall system productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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