***Original Research Article***

**Growth behavior and Productivity of Intercrops under *Gmelina arborea* based agroforestry systems**

**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.*

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). 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, Singh *et al.,* 2024 and Singh 2023).

. A *Gmelina arborea* based agroforestry system integrates this fast-growing, multipurpose tree with other crops and livestock, offering benefits like biomass production, carbon sequestration, and diverse resource utilization, particularly in regions like India. It have to belong in *Lamiaceae* family. *Gmelina* trees does not need extra water or nutrients, as it benefits from what is supplied to farming plants. Depending on growth conditions, including the soil and climate factors, pruning the side branches with secateurs once a year before the monsoon can enhance the overall growth of the tree.

*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 the one of the best option to produce the *Brassica juncia* (Mustard). This crop has to also using in agroforestry as an intercrops (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.

1. **MATERIAL 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.* T1- *Gmelina*-Arhar, T2 -*Gmelina*- cowpea, T3-*Gmelina*- mustard, T4- sole *Gmelina*, T5-sole arhar, T6- Sole cowpea, T7- sole mustard) and this combination was replicated by 3 time. The data analysis done by CRBD (Complete randomized block design).

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 1m² (1m x 1m) 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 amount 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:
* 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:

1. **RESULT AND DISCUSSION**
2. **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 T6 - Sole cowpea (59.00 m per row length) found maximum plant population to T1 - *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 T1 (25, 17.33 and 21.17 m/row length) at par with T5 (24.67, 21.67 and 23.17 m/row length), T2 (52.67, 46.67 and 21.17 m/row length) at par with T6 (59.00, 55.33 and 57.17 m/row length) and T3 (40.33, 38.33 and 39.30 m/row length) at par with T7 (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)

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **2019-20(Y1)** | **2020-21(Y2)** | **Pooled Mean** |
| T1(*Gmelina* Arhar) | 25.00 | 17.33 | 21.17 |
| T2 (*Gmelina* -Cowpea) | 52.67 | 46.67 | 49.67 |
| T3  (*Gmelina* - mustard) | 40.33 | 38.33 | 39.33 |
| T4 (Sole *Gmelina*) | - | - | - |
| T5 (Sole Arhar) | 24.67 | 21.67 | 23.17 |
| T6 (Sole Cowpea) | 59.00 | 55.33 | 57.17 |
| T7 (Sole mustard) | 42.67 | 39.00 | 40.83 |
| **Sem±** | 1.68 | 1.97 | 1.84 |
| **CD=** | 7.14 | 8.37 | 6.51 |

1. **Crop height (cm) under different land use system**

The Y1 when the *Gmelina* was 4 year old the crop height varied at harvest. *Gmelina* with arhar (T1) registered the maximum value whereas sole cowpea (T6) registered the lowest value. In Y2 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 (T1) accounted highest value and Sole Cowpea (T6) secured lowest value. The pooled values of crops height of both the year witnessed significant variation at harvest. *Gmelina* with Arhar (T1) significantly superior to all treatments except sole Arhar (T5) 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).

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **2019-20 (Y1)** | **2020-21 (Y2)** | **Pooled Mean** |
| T1 (*Gmelina* -Arhar) | 156.00 | 153.33 | 154.67 |
| T2 (*Gmelina* -Cowpea) | 135.67 | 131.67 | 133.67 |
| T3  (*Gmelina* - mustard) | 132.33 | 129.00 | 130.67 |
| T4 (Sole *Gmelina*) | - | - | - |
| T5 (Sole Arhar) | 143.00 | 140.67 | 141.83 |
| T6 (Sole Cowpea) | 115.33 | 109.67 | 112.50 |
| T7 (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.**

1. **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 (Y1) and second year (Y2) of the experiment across the crop seasons. In Y1, 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 (T1) showing the highest value, while cowpea grown alone (T6) recorded the lowest. In Y2, when the trees were 5 years old, there was a decrease in branches per plant compared to Y1, with variations also noted at harvest time. The average values from the treatments ranged from 3. 40 to 20. 13, where *Gmelina* with Arhar (T1) again demonstrated a significantly higher value, and cowpea grown alone (T6) 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 (T1) and sole Arhar (T5) 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

1. **Pod/silique branch-1 (Number) of crops**

Reviewing data in Table 3 and Figure 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 (T1), *Gmelina* with mustard (T3), and sole Arhar (T5) 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 (T1) having the highest values, followed by sole Arhar (T5) and then *Gmelina* with mustard (T3). T1 showed clear superiority over both T3 and T5. In many cases, *Gmelina* with Arhar (T1) was significantly better than all other treatments, showing a trend of values as follows: T1 > T5 > T3 > T2 > T7 > T6. 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(Y1)** | **2020-21(Y2)** | **Pooled Mean** | **2019-20(Y1)** | **2020-21(Y2)** | **Pooled Mean** | **2019-20(Y1)** | **2020-21(Y2)** | **Pooled Mean** |
| T1(*Gmelina* Arhar) | 20.40 | 20.13 | 20.27 | 18.67 | 20.33 | 19.50 | 427.15 | 402.13 | 414.64 |
| T2 (*Gmelina* -Cowpea) | 5.00 | 4.83 | 4.92 | 27.80 | 24.00 | 25.90 | 136.67 | 116.63 | 126.65 |
| T3  (*Gmelina* - mustard) | 5.57 | 4.67 | 5.12 | 37.40 | 35.33 | 36.37 | 206.46 | 158.73 | 182.60 |
| T4 (Sole *Gmelina*) | - | - | - | - | - | - | - | - | - |
| T5 (Sole Arhar) | 18.33 | 17.17 | 17.75 | 18.67 | 16.83 | 17.75 | 350.15 | 284.73 | 317.44 |
| T6 (Sole Cowpea) | 3.87 | 3.40 | 3.63 | 16.80 | 13.93 | 15.37 | 67.09 | 47.61 | 57.35 |
| T7 (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 |

1. **Pod/silique plant-1 (Number) of crops**

The analysis of data in Table 3 and Figure 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 (T1), *Gmelina* with mustard (T3), and sole arhar (T5) were significantly better than the other options. Additionally, T1 outperformed T3 while showing comparable results to T5. 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 (T1) showing the highest values, followed by sole arhar (T5) and then *Gmelina* with mustard (T3). T1 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 (T1) showed a significant superiority over all other treatments, following the trend of values as follows: T1 > T5 > T3 > T2 > T7 > T6. *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.

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

1. **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-1treatment *Gmelina* T3 significantly higher to all treatments followed by *Gmelina* with cowpea - T2 shows maximum in 1st year, 2nd year as well as pooled mean data respectively. Moreover, Sole cowpea- T6 (8.87, 5.00 and 6.93) and sole mustard - T7 (9.33, 5.03 and 7.18) were found partly correlated in both year and pooled mean. However, treatments Sole Arhar -T5 (3.90, 3.40 and 3.65) at par with *Gmelina* with Arhar- T1 (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).

**Table 4 Number of grain pod-1/silique-1 crops under different land use system**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **2019-20(Y1)** | **2020-21(Y2)** | **Pooled Mean** |
| T1 (*Gmelina* - Arhar) | 3.73 | 3.63 | 3.68 |
| T2 (*Gmelina* -Cowpea) | 10.33 | 9.17 | 9.75 |
| T3  (*Gmelina* - mustard) | 11.97 | 9.93 | 10.95 |
| T4 (Sole *Gmelina*) | - | - | - |
| T5 (Sole Arhar) | 3.90 | 3.40 | 3.65 |
| T6 (Sole Cowpea) | 8.87 | 5.00 | 6.93 |
| T7 (Sole mustard) | 9.33 | 5.03 | 7.18 |
| **Sem±** | 0.24 | 0.27 | 0.25 |
| **CD=** | 1.01 | 1.13 | 0.88 |

**Fig 3 Number of grain pod-1/silique-1 crops under different land use system**

1. **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 Y1 found *Gmelina* with mustard-T3 (44.44 q ha-1) and *Gmelina* with arhar -T1 (35.83 q ha-1) were significantly superior to *Gmelina* with Cowpea-T2 (29.17 q ha-1) sole arhar- T5 (28.22 q ha-1), sole cowpea- T6 (24.89 q ha-1) and sole mustard- T7 (28.83 q ha-1) whereas T2 and T7 significantly to T6 and T5. Moreover the T5 was at par with T6. The data in Y2 found under different treatments significantly the value of biological yield estimated in all treatments are maximum to minimum T1 (30.72 q ha-1) >T2 (25.67 q ha-1)>T5 (25.11 q ha-1)>T6 (22.00 q ha-1) >T3 (21.00 q ha-1) >T7 (15.56 q ha-1). In the pooled mean data have slightly change in yield sequence that is maximum to minimum T1 (33.28 q ha-1) >T3 (32.72 q ha-1)>T2 (27.42 q ha-1) >T5 (26.67 q ha-1) >T6 (23.44 q ha-1)>T7 (22.19 q ha-1).

Grain yield of cropsin first year (2019-20) was estimated in maximum under *Gmelina* with mustard (T3) value was 8.13, 6.06 and 7.09 q ha-1 and minimum found sole cowpea (T6) values. *Gmelina* with mustard (T3) significantly superior to *Gmelina* with arhar -T1 (5.91, 4.27 and 5.09 q ha-1) and sole cowpea –T6 (4.61, 3.27 and 3.94 q ha-1) , partly with *Gmelina*  with cowpea –T2 (6.94, 4.61 and 5.78 q ha-1), sole arhar –T5 (7.33, 5.67 and 6.50 q ha-1) and sole mustard – T7 (6.44, 5.11 and 5.78 q ha-1) respectively manner in 2021-22, and 2022-23 and pooled data .

Straw yield of cropsin Y1 the treatment *Gmelina* with mustard -T3 (36.31 kg ha-1) and *Gmelina* with arhar –T1 (29.92 q ha-1) were found significantly superior to treatments, whereas, the T3 was significantly maximum to T1. Moreover, the treatment sole cowpea- T6 (20.28 q ha-1), *Gmelina* with cowpea-T2 (22.22 q ha-1), sole arhar –T5 (20.89 q ha-1) and sole mustard – T7 (22.39 q ha-1) reflected as a partly. Straw yield in Y2 the treatment shows trend maximum to minimum in sequence of *Gmelina* with arhar –T1 (26.45 q ha-1) > *Gmelina* with cowpea- T2 (21.06 q ha-1) > sole arhar –T5 (19.44 q ha-1)followed by sole cowpea -T6 (18.73 q ha-1) > *Gmelina* with mustard -T3 (14.94 q ha-1) > sole mustard – T7 (10.44 q ha-1). Pooled mean data sequences of higher to lower shows that *Gmelina* with arhar –T1 (28.19 q ha-1) > *Gmelina* with mustard -T3 (25.63 q ha-1) > *Gmelina* with cowpea- T2 (21.64 q ha-1) > sole arhar –T5 (20.17 q ha-1)> sole cowpea -T6 (19.51 q ha-1) > sole mustard – T7 (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.

. **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(Y1)** | **2020-21(Y2)** | **Pooled Mean** | **2019-20(Y1)** | **2020-21(Y2)** | **Pooled Mean** | **2019-20(Y1)** | **2020-21(Y2)** | **Pooled Mean** |
| T1(*Gmelina* -Arhar) | 35.83 | 30.72 | 33.28 | 5.91 | 4.27 | 5.09 | 29.92 | 26.45 | 28.19 |
| T2 (*Gmelina* -Cowpea) | 29.17 | 25.67 | 27.42 | 6.94 | 4.61 | 5.78 | 22.22 | 21.06 | 21.64 |
| T3  (*Gmelina* - mustard) | 44.44 | 21.00 | 32.72 | 8.13 | 6.06 | 7.09 | 36.31 | 14.94 | 25.63 |
| T4 (Sole *Gmelina*) | - | - | - | - | - | - | - | - | - |
| T5 (Sole Arhar) | 28.22 | 25.11 | 26.67 | 7.33 | 5.67 | 6.50 | 20.89 | 19.44 | 20.17 |
| T6 (Sole Cowpea) | 24.89 | 22.00 | 23.44 | 4.61 | 3.27 | 3.94 | 20.28 | 18.73 | 19.51 |
| T7 (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 |

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

1. **Harvest index (%) of different agricultural crops**

The perusal of harvest index data Table 6. The harvest index data on 2019-20 (Y1) treatment *Gmelina* with Cowpea -T2 (23.72%), Sole Arhar-T5 (26.02%), and Sole Mustard- T7 (22.38%) were significantly to *Gmelina* with Arhar-T1 (16.48%), *Gmelina* with mustard-T3 (18.30%) and Sole cowpea-T6 (18.29%), whereas T7 at par with T2 and T5. The data trend in second year (2020-21) slightly changes to previous year the treatment *Gmelina* with mustard-T3 (29.70%) and Sole Mustard-T7 (33.46%) were estimated significantly superior to *Gmelina* with Arhar-T1 (13.91%), *Gmelina* with Cowpea-T2 (18.19%), Sole Arhar-T5 (23.00%) and Sole cowpea-T6 (15.04%), whereas T3 at par with T7. 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-T3, Sole Arhar-T5 and Sole Mustard- T7 were found significantly to other treatments *i.e.* *Gmelina* with Arhar-T1, *Gmelina* with Cowpea -T2 and Sole cowpea-T6. However, treatment *Gmelina* with mustard-T3, Sole Arhar-T5 and Sole Mustard-T7 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). Significant advances in wheat yields historically have come from breeding efforts that have aimed at improving HI.

1. **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 (Y1) of study it was observed that arhar in open (T5) condition exhibited highest quantity (4.40 q ha-1) and cowpea in open (T6) registered the lowest quantity (1.91 q ha-1). In 2020-21 (Y2) 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 T5> T3 >T1 > T7 > T2 >T6. 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).

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment/ Year** | **Harvest index** | | | **Arhar Equivalent yield** | | |
| **2019-20 (Y1)** | **2020-21 (Y2)** | **Pooled Mean** | **2019-20**  **(Y1)** | **2020-21**  **(Y2)** | **Pooled Mean** |
| T1(*Gmelina* Arhar) | 16.48 | 13.91 | 15.20 | 3.55 | 2.56 | 3.06 |
| T2 (*Gmelina* -Cowpea) | 23.72 | 18.19 | 20.96 | 2.87 | 2.08 | 2.47 |
| T3  (*Gmelina* - mustard) | 18.30 | 29.70 | 24.00 | 3.72 | 2.82 | 3.27 |
| T4 (Sole *Gmelina*) | - | - | - | - | - | - |
| T5 (Sole Arhar) | 26.02 | 23.00 | 24.51 | 4.40 | 3.40 | 3.90 |
| T6 (Sole Cowpea) | 18.29 | 15.04 | 16.67 | 1.91 | 1.47 | 1.69 |
| T7 (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 |

1. **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. A discernible trend of reduced productivity across most parameters was observed in the second year, suggesting an increasing competitive effect from the maturing *G. arborea* trees. 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

**Competing interest**

Not applicable.

**Ethical values**

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.

**References**

Burgess, A. J., Cano, M. E. C., & Parkes, B. (2022). The deployment of intercropping and agroforestry as adaptation to climate change. Crop and Environment, 1(2), 145-160. https://doi.org/10.1016/j.crope.2022.05.001

Do, V. H., La, N., Bergkvist, G., Dahlin, A. S., Mulia, R., & Öborn, I. (2025). Spatial and temporal variation in crop productivity and relation with soil fertility within upland agroforestry. Field Crops Research, 320, 109675. https://doi.org/10.1016/j.fcr.2024.109675

Singh, K., Bhardwaj, D. R., Kaushal, R., Sharma, S., & Kumar, A. (2024). Evaluation of turmeric (Curcuma longa L.) productivity and economics under Melia composita Willd. based agroforestry system in the mid-hills of Northwestern Himalayas: Effects of tree spacing and use of vegetative mulch. Agroforestry Systems, 98, 1303–1322. https://doi.org/10.1007/s10457-024-01001-x

Singh, K. (2023). Optimisation of tree spacing and mulch materials on Curcuma longa L. crop productivity under Melia composita Willd. based agroforestry system (Doctoral dissertation). Dr. YSP University of Horticulture and Forestry, Nauni, Solan H.P.

Tripathi, M. K., Saini, B. C., & Chaturvedi, S. (2006). Growth and yield of intercropped wheat under Salix and Dalbergia agroforestry system. Annals of Biology, 22 (2).

Sarvade, S., Mishra, H. S., Kaushal, R., Chaturvedi, S., Tewari, S., & Jadhav, T. A. (2014). Performance of wheat (Triticum aestivum L.) crop under different spacings of trees and fertility levels. \*African Journal of Agricultural Research, 9(9), 866-873.

Singh, C., Dadhwal, K. S., Dhiman, R. C., Kumar, R., & Avasthe, R. K. (2012). Allelopathy effects of Paulownia and poplar on wheat and maize crops under agroforestry systems in Doon Valley. Indian Forester, 138(11), 142-144.

Puri, S., Bhawana, S., & Swamy, S. L. (2001). Growth and productivity of wheat varieties in an agrisilviculture system. Indian Journal of Agroforestry, 3(2), 134-138.

Shah, A. K., Kori, A. K., Kumar, K., & Dongre, R. (2022). Yield performance and economic evaluation of mustard varieties under mango based agri-horticulture practice in semi-arid tropics. Agroforestry Systems, 96, 651-657. https://doi.org/10.1007/s10457-021-00712-9

Banerjee, H., & Dhara, P. K. (2011). Evaluation of different agri-horti-silvicultural models for rainfed uplands in West Bengal. Progressive Agriculture, 11(1), 143-148.

Yang, Y., Hu, Y., Li, P., Hancock, J. T., & Hu, X. (2023). Research Progress and Application of Plant Branching. Phyton-International Journal of Experimental Botany, 92(3), 679-689. https://doi.org/10.32604/phyton.2023.024904

Assuero, S. G., & Tognetti, J. A. (2010). Tillering regulation by endogenous and environmental factors and its agricultural management. American Journal of Plant Sciences and Biotechnology, 4(1), 35-48.

Fu, Z., Chen, P., Zhang, X., Qin, X., Yang, F., & Zhang, W. (2023). Maize-legume intercropping achieves yield advantages by improving leaf functions and dry matter partition. BMC Plant Biology, 23, 438. https://doi.org/10.1186/s12870-023-04408-3

Li, C. T., Stomph, T. J., Makowski, D., Li, H., Zhang, C., Zhang, F., & van der Werf, W. (2023). The productive performance of intercropping. Proceedings of the National Academy of Sciences, 120(2), e2201886120. https://doi.org/10.1073/pnas.2201886120

Li, C., Zhang, F., Li, L., Yang, W., Raza, M. A., & van der Werf, W. (2020). Yield gain, complementarity and competitive dominance in intercropping in China: A meta-analysis of drivers of yield gain using additive partitioning. European Journal of Agronomy, 113, 125987.

Porker, K., Straight, M., & Hunt, J. R. (2020). Evaluation of G × E × M Interactions to Increase Harvest Index and Yield of Early Sown Wheat. Frontiers in Plant Science, 11, 994. https://doi.org/10.3389/fpls.2020.00994

Porter, J. R., & Semenov, M. A. (2005). Crop responses to climatic variation. Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1463), 2021-2035.

Suwa, R., Hakata, H., Hara, H., El-Shemy, H. A., Adu-Gyamfi, J. J., Nguyen, N. T., Kanai, S., Lightfoot, D. A., Mohapatra, P. K., & Fujita, K. (2010). High temperature effects on photosynthate partitioning and sugar metabolism during ear expansion in maize (Zea mays L.) genotypes. Plant Physiology and Biochemistry, 48(2-3), 124-130.

Lavanya, Y., & Kurhade, N. G. (2018). Growth, Yield Attributes and Yield of Pigeonpea + Niger Intercropping System as Influenced by Planting Pattern under Rainfed Condition of Marathwada Region. International Journal of Current Microbiology and Applied Sciences, 7(11), 2303-2309.

Rathod, P. S., Halikatti, S. I., Hiremath, S. M., & Kajjidoni, S. T. (2004). Influence of different intercrops and row proportions on yield and yield parameters of pigeonpea in Vertisols of Dharwad. Karnataka Journal of Agricultural Sciences, 17, 652-657.

ABBREVIATIONS

*Gmelina arborea = G. arborea, – Cajanus Cajan* = Arhar, *Vigna Unguiculata* = Cowpea, And *Brassica Juncea* =Mustard