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Influence of Tree Geometry on Growth and Yield of Mungbean (*Vigna radiata* L.) under Gamhar (*Gmelina arborea* Roxb.) based Agroforestry System

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ABSTRACT

The experiment was conducted during *kharif* (June to September) 2022–23 at Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, India to evaluate effect of *Gmelina arborea* geometry on the growth and yield of mungbean, tree growth, biomass, carbon storage and assessing the economic feasibility of the agroforestry systems. The experiment was designed for intercropping of one mungbean high yielding varieties viz., IPM 205-7 (Virat) sown in June with *Gmelina arborea*. The treatments for gamhar and mungbean are as follows: T_1-*Vigna radiata* sole crop; T_2-*Gmelina arborea* sole tree (5×5 m^2); T_3-*Gmelina arborea* sole tree (5×4 m^2); T_4-*Gmelina arborea* sole tree (5×3 m^2); T_5-*Gmelina arborea* (5×5 m^2)+*Vigna radiata*; T_6-*Gmelina arborea* (5×4 m^2)+*Vigna radiata*; T_7-*Gmelina arborea* (5×3 m^2)+*Vigna radiata*. Experiment was designed in randomized block design (RBD) with seven treatments and five replications. The effect of different spacing patterns viz., S_1-5×5 m^2, S_2-5×4 m^2, S_3-5×3 m^2 in 2 year old Gamhar plantation with seven treatments combinations on mungbean was studied at the Forestry Research Farm, RLBCAU, Jhansi. The maximum number of branches plant^{-1} (8.04), number of trifoliate leaves plant^{-1} (11.96), number of seeds pod^{-1} (12.32), grain yield (0.73 t ha^{-1}) and straw yield (2.13 t ha^{-1}) was recorded in mungbean sole crop. The plant height (62.51 cm) was recorded highest in mungbean intercrop in 5×3 m^2 gamhar spacing. The maximum girth (27.38 cm) of trees was recorded in 5×5 m^2 gamhar spacing mungbean intercrop. The tree height (6.01 m) and benefit cost ratio (2.67) was observed maximum in 5×4 m^2 gamhar spacing with mungbean intercrop.

KEYWORDS: Agroforestry, economics, gamhar-intercropping, mungbean, tree geometry, yield

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Agroforestry systems in India comprise both traditional and modern land use systems involving trees, agricultural crops, pastures and animal components. Agroforestry has tremendous potential (Kefale, 2020) and utility in many ways, such as providing employment to both rural and urban populations through production, processing, and value addition (Dagar et al., 2014; Yadav et al., 2016a). Agroforestry is the best alternative to conventional method of agriculture. Indigenous and Traditional Knowledge of Agroforestry (ITKAF) methods is critical to investigate and document for its improvement. Farmers hold the right to develop various agroforestry methods on their lands (Yadav et al., 2017; 2018a). An agroforestry system is only feasible if the tree and intercrop components complement each other (Yadav et al., 2018b). India's efforts in agroforestry research have been primarily self-funded. In India, agroforestry research has been patchy and had its ups and downs. Undoubtedly, a more planned, concentrated, and determined effort will provide more and better outcomes (Puri and Nair, 2004; Yadav et al., 2015).

Gamhar (*Gmelina arborea* Roxb.) is an indigenous fast-growing species known for its inherent disease, fire, and drought resistance. The high quality of Gamhar wood is excellent for a variety of applications including paper pulping, plywood or particleboard manufacturing, lumber, furniture and other forest based business. It is also known as white teak, and it is a tropical deciduous tree endemic to Asia's damp tropical woods (Khare, 2004). It is a low-light-demanding plant that is appropriate for agricultural forestry and large-scale afforestation/reforestation efforts (Verma et al., 2017). Apart from being a wood species, plant components such as the root, leaf, fruit, flower, and bark contain various therapeutic characteristics that have been employed in traditional medical traditions (Warrier et al., 2021).

Mungbean (*Vigna radiata* L.) is a self-pollinated leguminous crop produced in India's arid and semi-arid regions during the *kharif* (rainy) and summer seasons (Vara Prasad and Shiva Prasad, 2013). It is drought resistant and may be cultivated well in locations with irregular rainfall on well-drained loam to sandy loam soils (Asaduzzaman et al., 2010). After the pods have been harvested, the plants can be utilised as high-quality green or dry feed and green manure (Kumar and Kher, 2021). Almost 90% of global green gram output is generated in Asia, with India being the world's top producer, accounting for more than 50% of global production. Green gram is a short-season crop grown by the majority of Gujarat farmers (Kumar et al., 2018).

Spacing is the key silviculture method for promoting plantation development, directly responsible for increased yield. In general, wider spacing resulted in the highest tree height, diameter at breast height, clear bole height, crown width, individual tree volume, and utilisable biomass output tree^{-1}, whereas tighter spacing resulted in the lowest. Similarly, tighter spacing yielded the highest total wood biomass and volume output hectare^{-1} due to the greater number of trees present when compared to broader spacing regimes (Honfy et al., 2023). Agroforestry is a common method for modifying the microclimate in the field (Yadav et al., 2016b; 2016c). Trees primarily influence crop radiation, relative humidity, carbon dioxide content, wind velocity, and soil environment (Dhillon et al., 2016; Yadav et al., 2017). In light of the foregoing, the current study was carried out over the *kharif* season of 2022–23 to evaluate the growth and yield of mungbean under different tree geometry of *Gmelina arborea* and to study the effect of different spatial arrangements on tree growth, biomass and carbon storage. This study also aimed at assessing the economic feasibility of the various agroforestry systems.

2. MATERIALS AND METHODS

2.1. Details of the experimental site

This investigation was carried out during *kharif,* 2022–23 (June to September) at gamhar-agroforestry plantation in Forestry Research Farm situated at Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, India. The site is situated between 25° 30'–25' 32° N latitude and 78° 32'–78' 34° N longitude with an altitude of 272 m above mean sea level. The area is semi-arid with the average rainfall of the area is around 867 mm. The climate of the region ranges from warm subtropical to semi-arid. The soil found in this region is called Parwa. The texture of the soil ranges from loamy to sandy. These soils are productive despite their low organic matter content. The majority of the soil in this area has low nutritional value. In the course of *kharif,* 2021, daincha crop was raised in the plot. Prior to the current study, the plot was used to cultivate crops like chickpea, lentil, and Lathyrus.

2.2. Experimental details

The experiment was designed for intercropping of one mungbean high yielding varieties viz., IPM 205-7 (Virat) sown in June with *Gmelina arborea* which was planted in 2020 with three spacing of S_1 (5×5 m^2), S_2 (5×4 m^2) and S_3 (5×3 m^2). Experiment is designed in randomized block design (RBD) with seven treatments and five replications. It included different combinations of mungbean and gamhar in different spacings along with sole cropping's of mungbean and gamhar in different spacings. The treatments for gamhar and mungbean are as follows: T_1-*Vigna radiata* sole crop; T_2-*Gmelina arborea* sole tree (5×5 m^2); T_3-*Gmelina arborea* sole tree (5×4 m^2); T_4-*Gmelina arborea* sole tree (5×3 m^2); T_5-*Gmelina arborea* (5×5 m^2)+*Vigna radiata*; T_6-*Gmelina* *arborea* (5×4 m^2)+*Vigna radiata*; T_7-*Gmelina arborea* (5×3 m^2)+*Vigna radiata*.

2.3. Crop management and data recording

The recommended doses of N, P_2O_5, K_2O and S were 25, 40, 20 and 28 kg ha^{-1} respectively. Full dose of nitrogen, phosphorus, potassium in the form of urea and DAP were applied basal as per treatments. All other agronomic practices were adopted as per needs of the crop. Growth and yield attributes as mung height, number of branches $plant^{-1}$, number of trifoliate leaves $plant^{-1}$, emergence count, dry matter accumulation, leaf area, number of root nodules $plant^{-1}$, days taken to 50% flowering, number of pods $plant^{-1}$, number of seeds $plant^{-1}$ and test weight was recorded at three intervals i.e. 25 DAS, 45, DAS and 65 DAS by randomly selecting 5 plants in each replication and treatment.

The growth analysis parameters like crop growth rate, relative growth rate, net assimilation rate, leaf area ratio and leaf area index were also calculated. The maximum plant height was measured from the base of the stem to the tip of the longest trifoliate leaf. Number of pods in individual selected plant was counted at every picking and finally these were added to obtain the mean number of pods $plant^{-1}$. Yield $plot^{-1}$ was worked out for respective plots and expressed in kg. Yield $hectare^{-1}$ was calculated from the yield $plot^{-1}$ by making necessary conversions and it is expressed in tonne.

With respect to *Gmelina arborea* growth attributes namely, tree height (m) girth at breast height (cm), crown spread (m) and biomass carbon storage (Mg ha^{-1}) were documented before cultivation and after harvesting of the mungbean intercrop. The systems were also checked for their economic feasibility by the calculation of certain economic attributes i.e. cost of cultivation, gross returns, net returns and benefit cost ratio. The soil of the experimental site was also subjected to analysis. Various soil parameters such as soil EC, pH, soil organic carbon, available nitrogen, available potassium, available phosphorus were studied pre-cultivation and post-harvest. The soil samples were calculated from 0–15 cm depth from all replications and treatments.

2.4. Statistical analysis

Data was analysed statistically using Fisher's analysis of variance techniques and least significant difference test at 5% probability level was employed to test the significance among treatment's means. In accordance with the method recommended by Gomez and Gomez (1984), the data gathered was subjected to statistical analysis. OP-STAT software was used for the statistical analysis of the data. The statistically significant differences between the treatments in terms of growth and yield parameters were found using tests of significance (t-test). Plots were employed as the experimental units for all calculations and statistical analysis.

3. RESULTS AND DISCUSSION

3.1. Growth attributes for mungbean

Growth attributes (Table 1 and 2) of mungbean like number of trifoliate leaves $plant^{-1}$ (11.96), number of branches $plant^{-1}$ (8.04), dry matter accumulation (228.03 g m^{-2}), crop growth rate (12.96 g m^{-2} day^{-1}), relative growth rate (4.33 mg g^{-1} day^{-1}), net assimilation rate (1.83 g m^{-2} day^{-1}) and leaf area index (17.38) was observed to be maximum in T_1 i.e. mungbean sole crop. T_1 also took the least number of days (31) to attain 50% flowering while T_7 (gamhar (5×3 m^2)+mungbean) took the longest (35). The plant height (62.51 cm) and leaf area ratio (220.97 cm^2 g^{-1}) was recorded maximum in T_7 i.e. gamhar (5×3 m^2)+mungbean. The other growth attributes like leaf area (50.79 cm^2) and number of root nodules $plant^{-1}$ (13.69) was found highest in T_5 i.e. gamhar (5×5 m^2)+mungbean. The germination count (29) was recorded maximum in T_6 (gamhar (5×4

Table 1: Growth attributes of mungbean under various spatial arrangement of gamhar

Treatment	Height of the plant (cm)	No. of trifoliate leaves $plant^{-1}$	No. of branches $plant^{-1}$	Dry matter accumulation (g m^{-2})	Leaf area (cm^2)	No. of root nodules $plant^{-1}$	Emergence count	Days taken for 50% flowering
T_1	55.22	11.96	8.04	228.03	48.78	13.04	24.00	31.00
T_2	-	-	-	-	-	-	-	-
T_3	-	-	-	-	-	-	-	-
T_4	-	-	-	-	-	-	-	-
T_5	60.86	6.82	6.43	133.96	50.79	13.69	22.00	32.00
T_6	58.91	6.70	5.67	103.57	46.80	12.02	29.00	33.00
T_7	62.51	6.28	5.41	88.72	48.26	11.77	26.00	35.00

T_1: *Vigna radiata* sole crop; T_2: *Gmelina arborea* sole tree (5×5 m^2); T_3: *Gmelina arborea* sole tree (5×4 m^2); T_4: *Gmelina arborea* sole tree (5×3 m^2); T_5: *Gmelina arborea* (5×5 m^2)+*Vigna radiata*; T_6: *Gmelina arborea* (5×4 m^2)+*Vigna radiata*; T_7: Gmelina *arborea* (5×3 m^2)+*Vigna radiata*

Table 2: Growth analysis of mungbean under various spatial arrangement of gamhar

Treatment	Crop growth rate ($g\ m^{-2}\ day^{-1}$)	Relative growth rate ($mg\ g^{-1}\ day^{-1}$)	Net assimilation rate ($g\ m^{-2}\ day^{-1}$)	Leaf area ratio ($cm^2\ g^{-1}$)	Leaf area index
T_1	12.96	4.33	1.83	129.91	4.54
T_2	-	-	-	-	-
T_3	-	-	-	-	-
T_4	-	-	-	-	-
T_5	12.37	4.13	1.57	211.45	3.60
T_6	12.41	4.14	1.52	172.68	3.46
T_7	12.47	4.16	1.48	220.97	2.84

m^2)+mungbean). This reduction in growth attributes of intercrop in agroforestry systems was also discussed by Ajaykumar et al. (2021). Similarly, the increase in height of intercrop in closely spaced tree rows was also reported by Kumar et al. (2017).

3.2. Yield attributes of mungbean

The yield attributes of mungbean like number of pods plant^{-1} (17.38), number of seeds pod^{-1} (12.32), test weight (41.39 g), biological yield (2.87 t ha^{-1}), grain yield (0.73 t ha^{-1}) and straw yield (2.13 t ha^{-1}) was observed maximum in T_1 i.e. mungbean sole crop (Table 3). On the other hand, the harvest index (27.28%) and grain to straw ratio (0.38) was observed maximum in T_6 i.e. gamhar (5×4 m^2)+mungbean. The general decrease in the yield of the intercrop in agroforestry systems was reported by Zahoor et al. (2021) and Corpuz (2013). Similarly the increase in the yield of the intercrop along with the increase in the tree spatial arrangements was also reported by Swamy et al. (2020).

Table 3: Yield attributes of mungbean under different spatial arrangements of gamhar

Treatment	No. of pods plant^{-1}	No. of seeds pod^{-1}	Test weight (g)	Biological yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	Grain to straw ratio
T_1	17.38	12.32	41.39	2.87	0.73	2.13	25.59	0.34
T_2	-	-	-	-	-	-	-	-
T_3	-	-	-	-	-	-	-	-
T_4	-	-	-	-	-	-	-	-
T_5	14.89	11.41	40.27	2.61	0.70	1.92	26.60	0.36
T_6	11.86	10.49	38.14	2.55	0.65	1.86	27.28	0.38
T_7	10.06	10.47	36.61	2.39	0.62	1.77	26.46	0.35

T_1: *Vigna radiata* sole crop; T_2: *Gmelina arborea* sole tree (5×5 m^2); T_3: *Gmelina arborea* sole tree (5×4 m^2); T_4: *Gmelina arborea* sole tree (5×3 m^2); T_5: *Gmelina arborea* (5×5 m^2)+*Vigna radiata*; T_6: *Gmelina arborea* (5×4 m^2)+*Vigna radiata*; T_7: Gmelina *arborea* (5×3 m^2)+*Vigna radiata*

3.3. Growth attributes of gamhar

The data pertaining to the growth of gamhar under different spatial arrangements are represented in Table 4. The maximum girth at breast height (27.38 cm) was observed in T_5 i.e. gamhar (5×5 m^2)+mungbean. The tree height (6.01 m) and crown spread (3.89 m) has been observed to be maximum in T_6 i.e. gamhar (5×4 m^2)+mungbean. The biomass carbon storage (6.58 Mg ha^{-1}) was maximum in T_7 i.e. gamhar (5×3 m^2)+mungbean. The better performance of trees in agroforestry intercropping systems were also discussed by Egbewole et al. (2018), Kumar et al. (2017), Yadav et al., 2017 as well as Vanlalngurzauva et al. (2020). This can be attributed to the nitrogen fixing ability of the legume intercrops, since gamhar is a non-nitrogen fixing species and makes use of the nitrogen fixed by the intercrops. Numerous factors viz., age, arrangement and management of the systems affect growth and productivity of trees (Yadav et al., 2015; Yadav et al., 2017; Yadav et al., 2018a).

3.4. Economic analysis of agroforestry systems

The economic analysis of the various treatments is represented in Table 5. The benefit cost ratio of the systems varied from 1.26 of sole cropped mungbean to 2.67 of mungbean intercrop with gamhar intercrop. The cost of cultivation was maximum for T_7 i.e. gamhar (5×3 m^2)+mungbean (₹ 78,720); gradually decreasing with increase in spacing and it is the minimum for T_2 i.e. gamhar

Table 4: Growth attributes of gamhar under various combinations of intercropping and spatial arrangements

Treatment	Height of the tree (m)	Girth at breast height (cm)	Crown spread (m)	Biomass carbon storage (Mg ha^{-1})
T_1	-	-	-	-
T_2	3.16	22.05	2.58	1.67
T_3	4.17	22.09	2.81	3.09
T_4	3.71	16.73	2.59	3.29
T_5	4.89	27.38	3.33	3.95
T_6	6.01	25.43	3.89	6.58
T_7	4.96	20.83	3.37	5.43

Table 5: Economic analysis of gamhar and mungbean based agroforestry systems

Treatment	Cultivation cost (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit-cost ratio
T_1	48,200	60,871	12,671	1.26
T_2	25,200	45,268	20,068	1.80
T_3	27,200	64,010	36,810	2.35
T_4	30,520	71,896	41,376	2.36
T_5	73,400	1,43,572	70,172	1.96
T_6	75,400	2,01,108	1,25,708	2.67
T_7	78,720	1,92,325	1,13,604	2.44

1 US$=80.22 INR

(5×5 m^2) sole tree (₹ 25,200). This is due to the increase in the number of trees with lower spatial arrangements i.e. lesser the spacing, higher the soil preparation work. The gross returns was obtained maximum from T_6 i.e. gamhar (5×4 m^2)+mungbean (₹ 2,01,108). This is attributed to the higher number of trees in 5×4 m^2 spacing compared to 5×5 m^2 spacing. However, T_7 doesn't have maximum gross returns due to the fact that the yield of the intercrop is reduced in lesser tree geometry. Accordingly, T_6 i.e. gamhar (5×4 m^2)+mungbean provided the maximum net returns (₹ 1,25,708) and thus the maximum benefit cost ratio (2.67). The cost-benefit ratio in different agroforestry systems have also been recorded ranging from 2.07 to 2.53 (Yadav et al., 2018c). The benefit-cost ratio of different agroforestry systems in the range of 1.87–5.7 have been reported by many researchers (Dhyani et al., 1996; Kumar et al., 2002; Bhatt and Mishra, 2003; Sharma, 2007) in various parts of India.

3.5. Soil analysis

The analysis of soil samples for soil EC, pH, organic carbon and available NPK post-harvest revealed the following results as postulated in Table 6. After harvest of mungbean, the available soil nutrients had increased slightly. EC showed a very slight increase whereas pH of the soil also showed a negligent decrease. The nutrients were found in higher concentrations in closer spacing. N, P and K showed a 2–5% increase. The maximum quantity of available nitrogen (142.33 kg ha^{-1}) and potassium (246.18 kg ha^{-1}) was present in mungbean sole crop i.e. T_1. Available phosphorus (10.34 kg ha^{-1}) was observed maximum in T_7 i.e. gamhar (5×3 m^2)+mungbean. The organic carbon of the soil improved by 6%. Similar results have been also observed by Vanlalngurzauva et al. (2020) and Swamy et al. (2020).

Table 6: Soil analysis data for gamhar and mungbean based agroforestry system

Treatment	EC (dS m^{-1})	pH	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
T_1	0.287	7.69	0.27	142.33	9.98	246.18
T_2	0.288	7.03	0.29	133.83	9.76	220.92
T_3	0.294	6.47	0.30	128.15	10.17	230.16
T_4	0.296	6.17	0.31	135.19	9.87	226.12
T_5	0.299	6.59	0.30	133.21	9.94	229.61
T_6	0.333	6.53	0.31	137.30	10.03	231.05
T_7	0.338	6.88	0.32	139.05	10.34	236.91
CD (p=0.05)	0.029	0.48	0.019	5.55	NS	NS
SEm±	0.010	0.16	0.007	1.90	0.13	7.17
CV	7.18	5.44	4.87	3.14	2.86	6.92

4. CONCLUSION

Better dimensions of gamhar growth parameters were observed in intercropping systems and mungbean could be cultivated as an intercrop between wider spaced tree rows.

5. FURTHER RESEARCH

Tree-crop interaction studies are the prime importance for the agroforestry system to justify the productivity alterations compared to mono-cropping. This study is needed to be replicated in different agroforestry systems with different multipurpose Tree species (MPTs). However, this is also required to investigate the effect of trees on crops with advancement of the age.

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