Environment and Ecology 42 (3B) : 1388—1396, July—September 2024
Article DOI: https://doi.org/10.60151/envec/LORB5986
ISSN 0970-0420

Tree Biometrics and Rhizosphere Microbial Population on Different *Gmelina arborea* Provenances

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Received 26 February 2024, Accepted 15 July 2024, Published on 4 September 2024

ABSTRACT

A study was conducted at All India Co-ordinated Research Project on Agroforestry, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India, from June 2021 to June 2023. It was laid out in Randomized Block Design with three replications and seven treatments of *Gmelina arborea*, viz., T_1 (Chandaka), T_2 (Nuapada), T_3 (Nilgiri), T_4 (Rayagada), T_5 (Durgaprasad), T_6 (Jhargram) and T_7 (Kahikuchi). This study revealed notable variations in growth and other parameters across provenances (treatments). The tree growth indicators were statistically significant. T_6=Jhargram provenance of *Gmelina arborea* consistently exhibited the highest performance, with biometrics such as tree height, DBH, crown spread, number of branches, and basal girth was 6.30 m, 10.24 cm, 1.98 m, 13 and 29.43 cm, respectively, however T_3=Nilgiri provenance showed the lowest overall tree biometrics. The above ground biomass, below ground biomass, total biomass production, and carbon sequestration in the *Gmelina arborea* were maximum in T_6=Jhargram provenance viz., 13.68 t/ha, 3.81 t/ha, 17.49 t/ha and 8.74 mg C/ha respectively. The available N was highest (173.49 kg/ha) in T_6. The available P and K were highest in T_7 viz. 49.66 kg/ha and 49.69 kg/ha respectively. The CFU (Colony Forming Units) in fungi and bacteria were maximum in T_6 69.70 × 10^4/ml g and 389.17 × 10^6/ml g respectively. However in actinomycetes, the CFU was highest in T_1 (337.49 × 10^6 /ml g). The highest litterfall occurred in February (58 g/m^2). The treatment T_6 as the most productive, with the highest overall yield (timber +fuel wood) of 332.05 t/ha. T_6=Jhargram provenance also gave the highest net return (Rs13.03 lakhs) per hectare with a BCR (3.89).

Keywords Tree biometrics, Carbon sequestration, Rhizosphere microbial population, Biomass production, Litter dynamics.

INTRODUCTION

Agroforestry represents an innovative approach to land utilization that holds promises in addressing social, economic, and environmental challenges. The role of forestry in reducing carbon emissions and enhancing carbon sequestration is widely recog-

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nized. The versatile tree *Gmelina arborea*, commonly referred to as Kashmir Teak, White Teak or Gambhar, is a naturally fast-growing species extensively utilized in forest-based industries for various timber-related products. This tree serves both industrial and domestic purposes, belonging to the Lamiaceae family shares similarities with Teak in terms of quality timber and workability. *Gmelina arborea* is an excellent option for large-scale reforestation, afforestation initiatives, and agricultural forestry. It is readily available across the country, spanning sub-mountainous, plains and peninsular regions. The light weight wood derived from this species finds applications in construction, packaging, furniture, particle board, plywood and wooden handicrafts, showcasing its versatility. *Gmelina arborea* plantations have been established and nurtured in tropical and subtropical regions, encompassing small woodlots, home gardens and agroforestry setups (Verma and Mathur 2018). Microbial communities within the rhizosphere of a tree play a role in enhancing plant growth through their impact on soil chemical properties and interactions with plant roots. It is believed that soil microbes are essential for preserving soil health, production quality and sustainability. Soil microbes are essential for nutrient cycling, soil stabilization and organic matter decomposition. While many works have been done in the processing aspects of *Gmelina arborea*, however, very little information is known about tree biometrics and rhizosphere microbial population and litterfall dynamics of Gambhar provenances. Considering the above facts, an experiment was done at the Agroforestry Research Station, OUAT Bhubaneswar.

MATERIALS AND METHODS

The current experiment was executed at the Agroforestry Research Station, Ghatika, Bhubaneswar of All India Co-ordinated Research Project on Agroforestry, Odisha University of Agriculture and Technology, Bhubaneswar during June 2021 to June 2023. The experimental plot is geographically positioned at 20º15' North longitude and 85º52' East latitude having an elevation of 25.9 meters ASL. The area has a tropical hot and humid climate, with rainfall of 1472 mm, average maximum temperature of 32.7ºC and minimum temperature of 25.2ºC. The soil is chiefly red lateritic, that has loamy sand to sandy loam texture. The soil samples were taken from the depth of 0–15 cm, using all of the recommended soil sampling protocols. The experiment was laid out in a Randomized Block Design (RBD) with three replications. The system comprised one silvi-tree species i.e., *Gmelina arborea* (Kashmir Teak/Gambhar) which were collected from seven different provenances.T_1= Chandaka (Odisha), T_2 = Nuapada (Odisha), T_3 = Nilgiri (Odisha), T_4=Rayagada (Odisha), T_5=Durgaprasad (Odisha), T_6 =Jhargram (West Bengal), T_7=Kahikuchi (Assam). The experiment plot consisted of small plots of size 14 m × 8 m for different treatments per the layout plan. In each plot clods were broken for leveling and proper weeding was done. The *Gmelina arborea* trees were planted in 2015 by transplanting one-year-old saplings with a spacing of 6 m × 4 m with a recommended package of practices.

The height of the *Gmelina arborea* was measured vertically from ground level to the leading shoot with a digital Hypsometer. The stem thickness was measured at the collar region from randomly selected trees from each treatment with a caliper at different intervals and the mean was expressed in cm. The DBH was measured at breast height, using a caliper. The crown spread was measured along the widest diameter in the East-West direction and the North-South direction with the help of a measuring tape. In each experimental trial, the total number of branches was counted for every tree, and after that average was calculated.

The above ground biomass was calculated by using allometric equation :

$$0.1245 \times (\mathrm{DBH})^{(2.4163)}$$ (Hung *et al.* 2012)

The below ground biomass of trees was calculated as a factor of 0.26 of the above ground biomass (Cairns *et al.* 1997 and IPCC 2003). The total biomass is calculated by adding the above ground biomass and below ground biomass.

The parameters such as soil organic carbon (SOC), bulk density (BD), were estimated by following the formula (Singh *et al.* 2008).

Soil organic carbon= (Soil bulk density (g/cm^3)×Soil depth (cm) ×OC (%)) ×100

The total carbon stock of the tree was calculated by assuming 50% of the total biomass as carbon (Ravindranath *et al.* 1997). The litterfall of the trees was collected at monthly intervals over a period of two years. In each plot, quadrates of 1 m × 1 m size of litter trap were placed in each treatment to collect litter fall.

Using a glass electrode pH meter, the pH of the soil was tested in a 1:2 soil and water suspension (Jackson 1967). Similarly, the electrical conductivity (EC) was measured by using the conductivity meter in the 1:2 soil water suspension (Jackson 1967). The organic carbon content (OC) of the soil sample was determined by the rapid titration process of Walkley and Black (Piper 1950). Available N was calculated by alkaline potassium permanganate Subbiah and Asija (1956). Available P was determined by the Olsen method as suggested by Jackson (1967) and the available K was determined using the Flame Photometry method suggested by Meston (1956).

Fresh soil samples from individual plots in all three replications were collected and pooled together and removed the gravel, stubbles, roots and other waste materials, sieved with a 0.5 mm sieve, properly labeled, preserved in refrigerator at 4°C and the composite samples used for enumeration of microbial counts and estimation of enzyme activities. A wide variety of microorganisms can be isolated from the soil samples and grown on media in the laboratory. Different media encourage the growth of different types of microbes through the use of inhibitors and specialized growth substrates which are capable of growing on a specific media. These counts are referred to as "Colony-Forming Units" (CFUs).

CFU/ml/g = No. of colonies observed / Dilution factor × quantity of soil taken

The serial dilution of the soil sample was obtained by spread plating method. The principle of this method is that when microorganisms are grown through this method, all living propagules will grow and develop individual colonies. Soil dilution plates were prepared from fresh soil on the day of sampling. Hence by enumerating these colonies which develop on a specific growth medium, the number of viable cells of a particular group of organisms present in soil can be ascertained (Wollum 1982). After the serial dilution, 1 ml of the required dilution (10^4 for fungi and 10^6 to 10^6 for bacteria and actinomycetes, respectively) was inoculated into the respective petri-plates. The number of CFU/g dry soil was estimated by taking the soil dilution factor and soil moisture content into account.

To compare the profitability of various treatments, a comprehensive economic analysis was carried out. The cost of the output of the various agricultural systems was estimated and translated to the value per hectare, then the return of each procedure was determined and the net return (Rs/ha) was determined by subtracting the cost of cultivation from the gross return received. The Benefit Cost Ratio (BCR) was determined by dividing the net return by the cost of cultivation and provided to measure the profitability of the various treatments.

Data from multiple experiments is subjected to statistical analysis following the required "Analysis of Variance" procedure. With the aid of the 'F' test (Variance ratio), the magnitude of the treatment effect was tested. The mean treatment differential was evaluated using the Least Significant Difference (LSD)/ Critical Difference (CD) at a 5% likelihood range (Gomez and Gomez 1976).

When the treatment difference is greater than or equal to the critical difference it is significant otherwise there is no significant difference between the treatment means. The standard mean error (SEm±) and LSD were determined for further comparison when the variance ratio (F test) was found to be important at a 5% level of significance.

$$\text{SEm}\pm = \sqrt{\frac{\text{Error sum of square}}{n}}$$

Where, n = Number of observations LSD/CD at 5% = SEm ± × √2 × t value at 5% error degree of freedom.

RESULTS AND DISCUSSION

The data on the performance of total growth of different *Gmelina arborea* provenances revealed significant variation. This is attributed to variations in tree height, basal girth, DBH, crown spread, and total number of branches of seven different *Gmelina arborea* provenances (treatments).

Tree biometrics : The analysis of tree biometrics of *Gmelina arborea* under seven distinct provenances was statistically significant (Table 1).

***Tree height* :** The variation in tree height in *Gmelina arborea* provenances has been reported by many researchers Vongkhamho *et al.* (2022). T_6= Jhargram put out the mean total height 6.30 m, followed by T_1= Chandaka 5.67 m. The lowest height within the investigation period was recorded in T_3= Nilgiri 4.37 m. The trend in tree height at the end of the experiment was: $T_6 > T_1 > T_5 > T_7 > T_2 > T_4 > T_3$. This is due to the climatic conditions, nutrient uptake, microbial population present in the soil, and genetics of the tree species.

***Basal girth* :** The basal girth in *Gmelina arborea* provenances was observed to be highest in T_6=Jhargram, 29.43 cm, followed by T_1= Chandaka 27.26 cm, and T_3= Nilgiri had the lowest basal girth of 22.50 cm. The basal girth trend observed at the end of the experiment was: $T_6 > T_1 > T_4 > T_5 > T_2 > T_7 > T_3$.

***Diameter at breast height (DBH)* :** The DBH of the *Gmelina arborea* provenances showcased the highest DBH in T_6= Jhargram, 10.24 cm, followed by T_1= Chandaka, 8.68 cm, and the lowest was observed in T_3= Nilgiri 6.33 cm followed by T_2= Nuapada 7.87 cm. The trend in DBH at the end of the experiment was: $T_6 > T_1 > T_4 > T_7 > T_5 > T_2 > T_3$. The similar observation also found by Ige *et al.* (2013).

***Crown spread* :** The highest crown spread was observed in T_6= Jhargram, 1.98 m and the lowest was observed in T_3 = Nilgiri, 1.29 m. The trend in crown spread at the end of the experiment was: $T_6 > T_2 > T_4 > T_1 > T_5 > T_7 > T_3$. This can be due to environmental factors, such as soil composition, precipitation levels, and sunlight availability, which may influence the development of such canopies.

***Total number of branches* :** The maximum no. of branches was recorded inT_6= Jhargram, i.e., 13, and T_3= Nilgiri had the lowest no. of branches, i.e., 6.67. The trend in total number of branches at the end of the experiment was : $T_6 > T_5 > T_1 > T_7 > T_4 > T_2 > T_3$.

Biomass production : The analysis of biomass production of *Gmelina arborea* under seven distinct provenances was statistically significant (Table 2).

***Above ground biomass* :** The above ground biomass was found highest in T_6= Jhargram, 6.30 t/ha and on the other hand the lowest was observed in T_3 = Nilgiri 4.37 t/ha. The trend in above ground biomass at the end of the experiment was :$T_6 > T_5 > T_1 > T_4 > T_2 > T_7 > T_3$.

***Below ground biomass* :** The maximum below

Table 1. Tree biometrics of *Gmelina arborea* in a block plantation under the agroforestry system (2021-22 and 2022-23, Two years pool data).

Treatments of *Gmelina arborea* provenances	Tree height (m)	Basal girth (cm)	DBH (cm)	Crown spread (m)	Total no. of branches
T_1= Chandaka, Odisha	5.67	27.26	8.68	1.53	10.67
T_2 = Nuapada, Odisha	5.46	25.77	7.87	1.78	8.00
T_3 = Nilgiri, Odisha	4.37	22.50	6.33	1.29	6.67
T_4 = Rayagada, Odisha	5.12	26.53	8.44	1.69	9.00
T_5 = Durgaprasad, Odisha	5.64	26.03	8.07	1.34	11.33
T_6 = Jhargram, West Bengal	6.30	29.43	10.24	1.98	13.00
T_7 = Kahikuchi, Assam	5.58	25.10	8.19	1.40	10.33
SEm (±)	0.04	0.25	0.05	0.089	0.11
CD (5%)	0.15	0.77	0.17	0.274	0.35

Table 2. Biomass production in *Gmelina arborea* in a block plantation under the agroforestry system (2021-22 and 2022-23, Two years pool data).

Treatments of *Gmelina arborea* provenances	Above ground biomass (t/ha)	Below ground biomass (t/ha)	Total biomass (t/ha)	Soil organic carbon (kg/ha)	Carbon sequestration potential (mg C/ha)
T_1= Chandaka, Odisha	12.54	3.26	15.80	301.02	7.90
T_2 = Nuapada, Odisha	11.86	3.08	14.94	313.20	7.47
T_3 = Nilgiri, Odisha	10.55	2.59	13.14	248.10	6.57
T_4 = Rayagada, Odisha	12.13	3.12	15.25	304.07	7.62
T_5 = Durgaprasad, Odisha	12.60	3.45	16.05	316.80	8.02
T_6 = Jhargram, West Bengal	13.68	3.81	17.49	295.29	8.74
T_7 = Kahikuchi, Assam	11.18	2.53	13.71	287.38	6.85
SEm (±)	0.53	0.06	0.19	1.92	0.09
CD (5%)	1.66	0.21	0.61	5.77	0.29

ground biomass was recorded in T_6= Jhargram, i.e., 3.81 t/ha, and T_3= Nilgiri had the lowest below ground biomass of 2.59 t/ha. The total biomass of *Gmelina arborea* was measured twice, in June 2021-22 (72 MAP) and June 2022-23 (96 MAP).The trend in below ground biomass at the end of the experiment was: $T_6 > T_5 > T_1 > T_4 > T_2 > T_3 > T_7$.

Total biomass **:** T_6= Jhargram had the highest total biomass of 17.49 t/ha, whereas T_3= Nilgiri had the lowest total biomass of 13.14 t/ha. The trend in total biomass at the end of the experiment was: $T_6 > T_5 > T_1 > T_4 > T_2 > T_7 > T_3$. The observed variations in growth within the silvicultural system can be attributed to a complex interplay of factors, prominently including soil characteristics, rates of nutrient uptake, and prevailing climatic conditions. These multifaceted elements collectively influence the overall health and productivity of the silvicultural system, shaping the dynamic patterns of growth over time. Similar findings were reported by Nayak *et al.* (2014).

Table 3. Month wise average litter fall amount of *Gmelina arborea* in a block plantation under the agroforestry system (2021-22 and 2022-23, Two years pool data).

Months (Investigation period)	Leaf litter fall (g/m²)	Woody litter fall (Twigs and branches) (g/m²)	Total litter fall (g/m²)
June	-	-	0
July	-	-	0
August	3.67	-	3.67
September	7.33	0.33	7.66
October	11.00	0.67	11.67
November	17.67	1.00	18.67
December	20.00	1.33	21.33
January	52.33	2.67	55
February	54.67	3.33	58
March	10.67	1.33	12
April	-	-	0
May	-	-	0
June	-	-	0
Total	177.34	10.66	188.00

Soil organic carbon : The analysis of the soil organic carbon levels revealed significant observations, T_5= Durgaprasad projected highest soil organic carbon, 316.80 kg/ha whereas, T_3= Nilgiri had the least outcome of 248.10 kg/ha. The trend in soil organic carbon at the end of the experiment was : $T_5 > T_2 > T_4 > T_1 > T_6 > T_7 > T_3$. Soil organic carbon serves as a crucial reservoir of nutrients for plant growth, and the measured levels align with the expectations of a nutrient-rich environment. The microbial activity fostered by higher organic carbon content contributes to nutrient cycling, enhancing the overall fertility of the soil. This fertility, in turn, is beneficial for supporting robust tree development.

Carbon sequestration **:** The analysis of the carbon sequestration revealed that the capability of *Gmelina arborea* under seven distinct provenances was statistically significant. The carbon sequestration in *Gmelina arborea* capacity was measured at two separate time intervals: June 2021-22 (72 MAP) and June 2022-23 (96 MAP). T_6= Jhargram had the highest carbon sequestration potential of 8.74 Mg C/ha, whereas T_3= Nilgiri had the lowest carbon sequestration of 6.57 Mg C/ha. Similar findings were reported by Swamy *et al.* (2005). The trend in carbon sequestration at

Table 4. Soil physico-chemical properties of *Gmelina arborea* in a block plantation under the agroforestry system (2021-22 and 2022-23, Two years pool data).

Treatments of *Gmelina arborea* provenances	pH	OC (%)	EC (dS/m)	Avl N (kg/ha)	Avl P_2O_5 (kg/ha)	Avl K_2O (kg/ha)
T_1= Chandaka, Odisha	5.06	0.46	0.013	164.43	40.54	147.10
T_2 = Nuapada, Odisha	5.08	0.47	0.014	170.52	49.17	142.60
T_3 = Nilgiri, Odisha	5.10	0.43	0.015	167.90	44.09	147.00
T_4 = Rayagada, Odisha	5.12	0.49	0.017	172.34	42.32	143.57
T_5 = Durgaprasad, Odisha	5.09	0.48	0.016	169.65	47.35	148.06
T_6 = Jhargram, West Bengal	5.13	0.45	0.014	173.49	48.12	142.39
T_7 = Kahikuchi, Assam	5.07	0.44	0.016	171.46	49.66	149.69
SEm (±)	0.005	0.004	0.0005	0.32	0.18	0.035
CD (5%)	0.017	0.014	0.0018	0.98	0.56	0.13
Initial soil fertility status (2015)	5.47	0.43	0.011	108.6	38.2	146.4

the end of the experiment was: $T_6 > T_5 > T_1 > T_4 > T_2 > T_7 > T_3$. Similar research results have been reported by Pacaldo (2015).

Litterfall production

The investigation into litterfall production in the study area revealed compelling patterns, particularly concerning monthly variations and the cumulative annual output. The highest monthly litterfall production was recorded in the month of February (58.00 g/m^2) marked as the peak month for litterfall which was followed by January exhibited the second-highest litterfall production with a value of 55.00 g/m^2 (Table 3). These findings indicated on the temporal dynamics of litterfall, highlighting distinct peaks during the winter months. The observed prominence of litterfall during February can be attributed to several environmental factors. In many ecosystems, winter months are associated with specific plant life cycles, shedding leaves or reproductive structures. This could be a contributing factor to the heightened litterfall during this period. Additionally, climatic conditions such as temperature and photoperiod might influence tree physiology and consequently, litterfall rates. Furthermore, the total annual litterfall production, cumulatively reaching 188.00 g/m^2, provides a comprehensive overview of the yearly dynamics (Table 3). This cumulative value reflects the combined influence of various factors, including vegetation types, climate, and ecological processes affecting litterfall throughout the year. Understanding the annual litterfall production is crucial for assessing the overall contribution of plant material to nutrient cycling and organic matter input in the ecosystem.

Physico-chemical properties of the soil : The variation in soil physico-chemical properties in *Gmelina arborea* provenances has been reported by Behera and Rout (2022).

pH **:** The pH analysis of the soil samples from various locations yielded noteworthy results, with T_6= Jhargram, exhibiting the highest pH value at 5.13, followed closely by T_4= Rayagada, with a pH of 5.12 and T_1 had the lowest overall pH at 5.06 (Table 4). The trend in pH at the end of the experiment was: $T_6 > T_4 > T_3 > T_5 > T_2 > T_7 > T_1$. These findings collectively indicate that the soils in the studied areas are characterized by a mildly acidic nature. The mildly acidic pH levels recorded in both Jhargram and Nuapada align with common soil classification criteria. Soils with pH values in this range are considered slightly acidic, which can have implications for nutrient availability and microbial activity. It is essential to recognize the influence of pH on soil chemistry, as it affects the solubility and accessibility of essential nutrients for tree growth.

Organic carbon **:** The examination of Organic Carbon (OC) content in the soil samples was highest in T_4= Rayagada, 0.49% and lowest in T_3= Nilgiri 0.43% (Table 4). The trend in OC at the end of the experiment was: $T_4 > T_5 > T_2 > T_1 > T_6 > T_7 > T_3$. This limited variability indicates a relatively consistent organic carbon concentration across the studied location, suggesting

Table 5. Microbial population study of *Gmelina arborea* in a block plantation under the agroforestry system (2021-22 and 2022-23, Two years pool data).

Treatments of *Gmelina arborea* provenances	Fungi CFU= 10^4/ml g	Actinomycetes CFU= 10^6/ml g	Bacteria CFU= 10^6/ml g
T_1=Chandaka, Odisha	58.51	337.49	306.47
T_2=Nuapada, Odisha	40.42	245.47	286.43
T_3=Nilgiri, Odisha	39.68	296.30	357.76
T_4=Rayagada, Odisha	56.83	287.73	374.78
T_5=Durgaprasad, Odisha	63.53	302.10	367.69
T_6=Jhargram, West Bengal	69.70	317.14	389.17
T_7=Kahikuchi, Assam	66.87	298.15	388.20
SEm (±)	1.13	3.52	4.49
CD (5%)	3.42	10.59	13.53
Initial microbial population status (2015)	31.52	233.43	270.89

a stable baseline for organic matter within the soil. The recorded range falls within the typical spectrum for soil organic carbon, and while it may not exhibit wide fluctuations, even small variations in organic carbon content can have significant implications for soil health and fertility.

Electrical conductivity **:** The analysis of Electrical Conductivity (EC) values across the different soil samples has revealed notable variations, with the highest EC recorded in the T_4 = Rayagada, at 0.017 dS/m. After T_4, T_7 = Kahikuchi, and T_5 = Durgaprasad, displayed the second-highest EC values at 0.016 dS/m. T_1= Chandaka had the lowest overall EC value at 0.013. The trend in EC at the end of the experiment was: T_4> T_7=T_5> T_3> T_2=T_6> T_1 (Table 4). These findings provide insights into the soil's salinity levels, which is a crucial parameter influencing soil quality and plant growth. The elevated EC value in the T_4 sample indicates a relatively higher concentration of dissolved salts in the soil. High EC values often correlate with increased salinity, which may pose challenges for tree growth.

Available nitrogen **:** The assessment of available Nitrogen (N) content in the soil samples has yielded significant insights, with T_6= Jhargram, emerging as the sample with the highest recorded value at 173.49 kg/ha. Following closely, T_4 = Rayagada, exhibited the second-highest available nitrogen content, measuring 172.34 kg/ha. T_1= Chandaka had the overall lowest available N content at 164.43 kg/ha (Table 4). The trend in available N at the end of the experiment was: T_6> T_4> T_7> T_2> T_5> T_3> T_1. These findings highlight spatial variability in soil nutrient availability, which is a critical factor influencing tree growth, and overall soil fertility. The elevated available nitrogen content in T_6= Jhargram indicates a potentially favorable condition for tree nutrient uptake and growth in that specific location.

Available phosphorus **:** The examination of available Phosphorus (P) content in the soil samples revealed noteworthy findings, with T_7 = Kahikuchi, emerging as the treatment with the highest recorded value for the nutrient. The available phosphorus content in T_7 = Kahikuchi was measured at 49.66 kg/ha (Table 4). The trend in available P at the end of the experiment was : T_7> T_2> T_6> T_5> T_3> T_4> T_1. These results signify a localized enrichment of phosphorus in the soil of T_7= Kahikuchi which holds implications for nutrient management in this area.

Available potassium : The available Potassium (K) content in T_7 = Kahikuchi was measured to be 149.69 kg/ha and the lowest was observed in T_6= Jhargram. The trend in available K_2O at the end of the experiment was : T_7> T_5> T_1> T_3> T_4> T_2> T_6. The variation in soil physico-chemical properties in *Gmelina arborea* provenances has been reported by Ediene *et al.* (2016).

Microbial population status : The microbial population status revealed that the different microorganisms present in the soil were fungi, actinomycetes, and bacteria (Table 5). The CFU (Colony Forming Units) in fungi was maximum in T_6=Jhargram, 69.70 × 10^4 /ml g, and the lowest was observed in T_3= Nilgiri. The trend in fungi population status at the end of the experiment was: T_6> T_7> T_5> T_1> T_4> T_2> T_3.

In actinomycetes, the CFU was highest in T_1=Chandaka, 337.49 × 10^6 /ml g, followed by T_6= Jhargram, 317.14 × 10^6 /ml g, and the lowest was observed in T_2= Nuapada, 245.47 × 10^6/ml g. The trend in actinomycetes population status at the end of the experiment was: T_1> T_6> T_5> T_7> T_4> T_3> T_2.

Table 6. Yield and economics of *Gmelina arborea* in a block plantation under the agroforestry system (2021-22 and 2022-23, Two years pool data).

Treatments of *Gmelina arborea* provenances	Yield of *Gmelina arborea* (t/ha) Timber wood	Fuel wood (Branches twigs)	Net return (Rs in lakhs/ ha)	BCR
T_1= Chandaka, Odisha	309.56	8.72	12.38	3.68
T_2=Nuapada, Odisha	290.19	8.39	11.41	3.39
T_3=Nilgiri, Odisha	215.24	7.98	7.64	2.27
T_4=Rayagada, Odisha	232.6	8.67	8.53	2.53
T_5=Durgaprasad, Odisha	220.87	9.34	7.96	2.37
T_6=Jhargram, West Bengal	321.69	10.36	13.03	3.87
T_7=Kahikuchi, Assam	283.71	8.31	11.07	3.29
SEm (±)	8.63	0.017	3.46	0.08
CD (5%)	25.89	0.052	1.61	0.29

In bacteria, the highest was recorded in T_6=Jhargram, 389.17 × 10^6 /ml g, and the lowest was recorded in T_2=Nuapada, 286.43 × 10^6/ml g. The trend in bacteria population status at the end of the experiment was: $T_6 > T_7 > T_4 > T_5 > T_3 > T_1 > T_2$. This enhancement in microbial growth from June 2021-22 to June 2022-23 could be linked to greater litterfall, organic matter present in the soil and climatic conditions.

Yield and economics : The variation in yield and economics in *Gmelina arborea* provenances has been reported by Saravanan (2012). The evaluation of *Gmelina arborea* across seven different provenances within the silviculture system has provided significant insights into both yield and economic parameters. T_6=Jhargram, emerged as the most productive provenance, exhibiting the highest overall yield at 332.05 t /ha, comprising both timber and fuelwood. Following closely, T_1= Chandaka, yielded 318.28 t/ha, showcasing a robust performance in terms of timber and fuelwood production. The trend in yield at the end of the experiment was : $T_6 > T_1 > T_2 > T_7 > T_4 > T_5 > T_3$.

The economic analysis further revealed the financial viability of these provenances. T_6=Jhargram, not only led in yield but also demonstrated the highest net return at Rs 13.03 lakhs/ha. This suggests that the economic benefits derived from the cultivation of *Gmelina arborea*, considering both timber and fuelwood production, were maximized in the Jhargram provenance. T_1= Chandaka, secured the second-highest net return at Rs 12.38 lakhs/ha, affirming its economic viability as well.T_3= Nilgiri had the lowest net return at Rs 7.64 lakhs /ha (Table 6). The trend in net return at the end of the experiment was : $T_6 > T_1 > T_2 > T_7 > T_4 > T_5 > T_3$.

The Benefit-Cost Ratio (BCR) offers additional insights into the economic efficiency of the different provenances. T_6=Jhargram stood out with the highest BCR at 3.87, indicating that for every unit of investment, there was a substantial return. On the other hand, T_3=Nilgiri exhibited the lowest BCR at 2.27, suggesting a comparatively lower economic efficiency. The trend in BCR at the end of the experiment was $T_6 > T_1 > T_2 > T_7 > T_4 > T_5 > T_3$.

These findings emphasize the significance of site-specific conditions and provenance selection in optimizing both yield and economic returns in *Gmelina arborea* cultivation. The success of T_6=Jhargram in terms of both yield and economic indicators underscores the importance of tailoring silvicultural practices to the specific characteristics of each provenance. It also highlights the economic potential of *Gmelina arborea* as a valuable timber and fuelwood resource, with implications for sustainable forestry management.

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