

Biophysical performance of different multipurpose trees species in Jharkhand, India

Bikash Das¹, Pradip Kumar Sarkar^{1,*}, Neelam Kumari¹, P. Dey², A. K. Singh¹ and B. P. Bhatt³

¹ICAR-Research Complex for Eastern Region, Research Centre, Ranchi 834 010, India

²ICAR-Indian Institute of Soil Science, Bhopal 462 038, India

³ICAR-Research Complex for Eastern Region, Patna 800 014, India

An experiment was conducted to evaluate the performance and characterize plant growth behaviour, light profile and soil fertility status of seventeen different trees (12 years old). The study indicated higher biomass production potential of *Gmelina arborea*, *Dalbergia sissoo* and *Leucaena leucocephala*. Higher photosynthetically active radiation value below tree canopy indicates compatibility of trees with a majority of agricultural crops. In the present study, a significant increase in pH and decrease in EC of trees were observed. The significant reduction in nutrients in different trees indicated a need for replenishment of nutrients in soil for maintaining soil fertility in agroforestry systems on long-term basis.

Keywords: Agroforestry, biophysical performance, CO2FIX model, multipurpose trees species, tree biomass.

THE physiography of Jharkhand state of India is characterized by light textured soil, undulating topography and high rate of soil erosion¹. The agrarian scenario of the region is generally rainfed where rice-based monocropping is the prevalent practice. The soils of the region are low in organic carbon and available phosphorus content with deficiency of boron and zinc. Under these conditions, the productivity of majority of agricultural crops is low leading to unprofitability of upland agriculture².

Soil without tree cover on hilly slope associated with more intensive agricultural practices is vulnerable to erosion and reduced fertility. Agroforestry can be one of the effective land-use management practices which can check land degradation³. The variety of products obtained from trees from agroforestry land-use practices are timber and other non-timber forest products such as fruits, seeds, bulbs, bark, fibres, roots, leaves, small wooden logs, firewood, etc.^{4,5}. Integration of multipurpose trees in the existing production system can effectively improve the overall profitability of farming in Jharkhand. Being a tribal-dominated area, multipurpose tree species (MPTs) have always been an integral part of agriculture of the state. Trees like *Gmelina arborea* (Gamhar), *Melia aze-*

darach (Bakaine), *Azadirachta indica* (Neem), *Terminalia arjuna* (Arjun), *Pongamia pinnata* (Karanj), *Dalbergia sissoo* (Shisham), etc. are commonly found in the farm areas of tribal farmers⁶. However, limited information is available on the comparative growth performance⁷ and biomass production potential of different timer trees and MPTs in Jharkhand. Suitability of a tree species to be integrated with agricultural crops depends on light profile below the canopy and this information is also not available for the timber trees and MPTs. Improvement in soil fertility through integration of trees is recorded in many agroforestry systems⁸, though it is limited regarding the acidic soil of Jharkhand⁹. Keeping this in view, an experiment was initiated at ICAR-Research Complex for Eastern Region, Research Centre, Ranchi during 2003 to evaluate the performance of different multipurpose trees. In the present article, an effort has been made to characterize the growth behaviour of 12-year-old 17 tree species, light profile below the tree canopy and changes in soil fertility induced by the trees.

Materials and methods

The study was conducted at Ranchi, Jharkhand (23°16'19.73"N and 85°20'49.99"E, altitude 657.76 m) during 2014–15. Data on different plant growth parameters, and light profile were recorded from 12-year-old plants of 17 species including timber and MPTs. The plants were planted at a spacing of 5 m × 5 m accommodating 400 plants per ha. Data were also recorded regarding the soil properties under different trees at depths of 0–15 cm and 15–30 cm.

Tree height was measured using RAVI/Haga altimeter. Trunk circumference at breast height was measured using a measuring tape. To derive the volume of tree, we used diameter at breast height (DBH) and height (H) of the tree. We recorded data for four years, viz. 2007, 2012, 2014 and 2015, and calculated average tree volume (V) of the particular tree species and current annual increment (CAI) using volume equations¹⁰, which were obtained by averaging the tree volumes (V_1 and V_2) after considering trees as average of cylindrical and conical shape.

*For correspondence. (e-mail: pradipsarkar.tripura@gmail.com)

$$\text{Tree volume, } V_1 (\text{m}^3 \text{ tree}^{-1}) = (\pi \times \text{DBH}^2 \times H)/4$$

(for cylindrical shape). (1)

$$\text{Tree volume, } V_2 (\text{m}^3 \text{ tree}^{-1}) = (\pi \times \text{DBH}^2 \times H)/12$$

(for conical shape). (2)

Thus

$$V (\text{m}^3 \text{ tree}^{-1}) = (V_1 + V_2)/2. \quad (3)$$

Other parameters like crown spread/radius¹¹, crown height¹² and light intensity¹² (measured in kLUX using LUX meter) were also measured. During data recording, light intensity was noted every minute and the mean of these was considered for final calculation of photosynthetically active radiation (PAR).

Leaf area (LA; cm²) was estimated based on the measurements of leaf length and/or leaf width which is an indirect non-destructive method. Leaf length (L) was measured from lamina tip to the point of petiole intersection along the midrib and width (W) was measured at the widest point perpendicular to the midrib. The leaf can be described by a shape between an ellipse (0.78) and a triangle (0.50) of leaf length and width since actual leaf area is generally larger than a triangle but smaller than an ellipse¹³. Specific leaf weight was calculated as the ratio of dry mass of leaf to leaf area. Leaf area index (LAI) of each species was estimated using a canopy analyser.

Estimation of tree biomass (by using CO2FIX model)

Input parameters for CO2FIX model

To quantify tree biomass of the MPTs, a dynamic carbon accounting model CO2FIX v3.1 was considered for assessing the baseline tree biomass and its simulated tree biomass over 20 years. The main parameters relevant to CO2FIX model are the cohort-wise values for the stem-CAI (m³ ha⁻¹ year⁻¹); relative growth of the foliage, branches, leaf and root with respect to the stem growth; turnover rates for foliage, branches and roots over the years; and climate data of the site, viz. annual precipitation (mm) and monthly values of minimum and maximum temperatures (°C) (Tables 1–4). Other inputs to the model include initial surface soil organic carbon (Mg C ha⁻¹), rotation length for the tree species, percentage of carbon contents in different tree parts, wood density and initial values of baseline carbon (Mg C ha⁻¹) in different tree parts¹⁴.

Soil parameters such as pH and EC were measured using standard procedures. Content of organic carbon was measured by Walkley and Black rapid titration method. Available elements like nitrogen (N) was determined by alkaline permanganate method, phosphorus (P) by Bray's method using ascorbic acid¹⁵ and potassium (K) was

determined by flame photometer in soil solution prepared in an extraction solution of normal ammonium acetate (pH 7.0)¹⁵.

Statistical analysis

The data was analysed using SYSTAT® 11 Statistics II by SYSTAT Software Inc., USA, used for computing basic descriptive statistics.

Results and discussion

Data on different plant growth parameters of both timber tree species and MPTs are presented in Table 5. Among timber trees, the plant height ranged between 4.9 m (*Dalbergia latifolia*) and 13 m (*D. sissoo*) whereas among MPTs, it ranged between 3.5 m (*Sapindus mukorossi*) and 9.1 m (*Leucaena leucocephala*). With respect to trunk circumference at breast height, maximum values among timber species and MPTs were recorded as 70.3 cm (*G. arborea*) and 96.6 cm (*M. azedarach*) respectively. The maximum tree volume was recorded in *G. arborea* (timber tree) and *M. azedarach* (MPTs). In Chhattisgarh, India, Naugraiya and Puri¹⁶ reported similar plant height of 7.5-year-old *L. leucocephala* although the value for *T. arjuna* was markedly lower than that in the present study. In Bijapur (Madhya Pradesh), Devarnavadagi and Murthy¹⁷ recorded slower growth rate of 3-year-old plants of *D. sissoo* than *L. leucocephala* in contrast to the present findings. Again, trunk diameter at breast height of *Albizia procera* was higher than that of *D. sissoo*, although the present study indicated statistically similar values in both the species. As the experimental sites are under the same agro-climatic conditions (Eastern Plateau and Hills), variation in agro-ecological conditions within the region might have contributed towards this contrasting result. Singh and Singh⁷ also reported variation in plant growth parameters of different MPTs under different sub-zones of eastern plateau and hill agro-climatic conditions. The maximum canopy spread was recorded in *A. procera* (timber tree) and *M. azedarach* (MPTs). The minimum canopy spread was recorded in *P. pinnata* followed by *Aegle marmelos*, and *A. indica* which suggested the suitability of these species to be planted at a closer spacing under different agroforestry systems. The crown volume of *M. azedarach* was significantly higher than other MPTs. Among the timber species, crown volume was recorded maximum in *G. arborea* which was at par with *A. procera*. Crown volume was found to be significantly and positively correlated (0.75) with trunk circumference. Hence, based on the overall plant growth parameters, *M. azedarach*, *L. leucocephala*, *G. arborea* and *D. sissoo* were found to be fast growing species; *A. marmelos*, *A. procera*, *D. latifolia*, *Embliba officinalis*, *Pterocarpus marsupium*, *Tectona grandis* and *T. arjuna* were found to

Table 1. Parameters used in CO2FIX model for simulating tree biomass components in different tree cohorts

Parameters	Cohorts		
	Slow growing trees ^a	Medium growing trees ^a	Fast growing trees ^a
Rotation years	90	50	10
Wood density (Mg DM m ⁻³)	0.67	0.65	0.61
Carbon content (% dry weight)	48	48	48
Turnover rate foliage	0.5	0.5	0.6
Turnover rate branch	0.02	0.04	0.02
Turnover rate root	0.02	0.1	0.2
Product allocation for thinning harvesting ^a			
Stem log wood	0.8	0.8	0.8
Stem slash	0.2	0.2	0.2
Branch log wood	0.8	0.8	0.2
Branch slash	0.2	0.2	0.8
Foliage slash	1	1	1
Foliage slash soil	0.7	0.7	0.7

^aAjit *et al.*¹⁴.

Table 2. Estimated current annual increment (CAI) of the stem volume growth (m³ ha⁻¹ year⁻¹) over years for three tree cohorts

Slow growing		Medium growing		Fast growing	
Age	CAI ^a	Age	CAI	Age	CAI
0	4.94	0	8.00	0	10.67
1	2.77	1	21.33	1	42.67
2	2.51	2	34.67	2	88.00
3	2.42	3	45.33	3	88.00
4	2.41	4	56.00	4	101.33
5	2.42	5	69.33	5	112.00
6	2.47	6	77.33	6	122.67
7	2.53	7	88.00	7	133.33
8	1.29	8	93.33	8	136.00
9	1.52	9	93.33	9	138.67
10	2.47	10	96.00	10	138.67

be medium growing species and *A. indica*, *Madhuca integrifolia*, *P. pinnata* and *S. mukorossi* were found to be slow growing species. It is worth noting that the species mostly known for the uses of their wood are fast growing whereas MPT species are found to be slow growing. Height of the first branch is the most important indicator of suitability of the species for high value timber purposes. Among the timber species evaluated, maximum value was recorded in case of *D. sissoo*.

Tree growth and development in agroforestry system primarily depend on two major factors, viz. total photosynthesis carried out by all trees in a stand and the fraction of photosynthate that is allocated to stemwood. The amount of foliage can be estimated indirectly by a range of non-destructive techniques¹⁸ whereas the photosynthetic rate is difficult to measure directly. Plant LA is an important determinant of light interception and conse-

quently of transpiration, photosynthesis and plant development¹⁹. In the present study, highest LA was recorded in *T. grandis* (timber) and *M. azedarach* (MPTs) (Table 6). However, the maximum specific leaf weight was recorded in *T. grandis* (timber) and *M. integrifolia* (MPT). LAI plays an essential role in theoretical production ecology¹¹. It is an important parameter in the functioning of forests, controlling plant development and exchange of energy between vegetation and atmosphere²⁰. In the present study, the value of LAI was maximum in *A. procera* (timber) and *M. azedarach* (MPT) (Table 6). LAI was found to be significantly correlated with crown volume (0.57) and canopy spread area (0.68).

PAR below the canopy was significantly higher in case of MPTs such as *P. pinnata*, *Acacia catechu*, *P. marsupium*, *M. integrifolia*, *A. indica*, *S. mukorossi*, *E. officinalis* and timber trees such as *G. arborea*, *D. latifolia* and *A. procera* which indicated their suitability to be integrated with majority of annual crops (Table 6). Interestingly, PAR below canopy was significantly and negatively correlated with the height of first branching (-0.57). The maximum values of absorbed or reflected PAR (PAR_{a/r}) were recorded in *T. grandis* (timber species) and *M. azedarach* (MPTs). Waring *et al.*¹⁸ stated that, within a single tree, more exposed foliage absorbs more radiation and has higher photosynthetic rates than shaded foliage. High amount of PAR_{a/r} indicated high rate of photosynthesis leading to high rate of tree growth of these species.

Estimation of biomass estimates and through sequential harvesting are useful for quantifying net primary productivity and carbon-cycle¹⁴. CO2FIX has been extensively used for estimating biomass and changes in soil carbon stocks for forestry, agriculture and agroforestry projects. In our study, the tree biomass of different AFS was found to be in the range of 41.92 Mg DM ha⁻¹ (*S. mukorossi*) to

Table 3. Relative growth of various tree components with respect to stem growth for tree cohorts (over years)

Parameters	Slow growing ^a		Medium growing ^a		Fast growing ^a	
	Age	Rates	Age	Rates	Age	Rates
Foliage	0	1.00	1	0.26	0	0.30
	10	0.50	5	0.63	2	0.44
	20	0.73	15	0.50	3	0.40
	30	0.64	20	0.38	4	0.38
	40	1.02	25	0.32	5	0.37
	50	1.12	30	0.50	6	0.32
	60	0.98			7	0.56
	70	0.91			8	0.58
Branch	0	0.20	1	0.44	0	0.25
	10	0.18	5	0.44	2	0.22
	20	0.15	15	0.33	3	0.18
	30	0.16	20	0.38	4	0.18
	40	0.16	25	0.32	5	0.21
	50	0.15	30	0.32	6	0.28
	60	0.14			7	0.43
	70	0.14			8	0.58
Root	0	0.40	1	0.44	0	0.30
	10	0.40	5	0.48	2	0.43
	20	0.39	15	0.63	3	0.58
	30	0.30	20	0.60	4	0.49
	40	0.31	25	0.77	5	0.36
	50	0.31	30	0.82	6	0.31
	60	0.29			7	0.47
	70	0.27			8	0.37

^aAjit *et al.*¹⁴.**Table 4.** Climate data of the study area

Month	Temperature (°C)		Rainfall during 2014–15 (mm)	Normal rainfall (mm)*
	Minimum	Maximum		
March	9.4	23.4	0.0	25.0
April	11.9	27.8	38.0	21.8
May	15.1	30.7	67.0	61.7
June	20.6	32.8	291.0	249.4
July	24.0	37.3	302.0	336.6
August	25.8	33.8	189.0	319.1
September	25.1	30.0	45.0	247.3
October	24.9	29.9	56.0	76.6
November	23.2	31.4	56.0	10.8
December	18.8	30.3	5.0	16.7
January	14.6	27.9	8.0	21.2
February	10.8	24.8	5.0	16.7

*From past recorded data of the institute (ICAR RCER, RC, Ranchi).

190.98 Mg DM ha⁻¹ (*G. arborea*) (Table 7). When simulated, the tree biomass of the respective AFS over a simulated period of 20 years was in the range of 134.91 Mg DM ha⁻¹ (*S. mukorossi*) to 469.39 Mg DM ha⁻¹ (*G. arborea* as fast growing timber tree). The biomass yield of *D. sissoo* and *L. leucocephala* was also significantly higher than other species. Onyekwelu²¹ also reported high biomass yield of *G. arborea* plantations (5–21 years

ages) in Nigeria (83.2 tonne ha⁻¹ in 5-year-old plant to 394.9 tonne ha⁻¹ in 21-year-old plants). For degraded red lateritic soils in Central India, Swami *et al.*²² recorded stand biomass yield of *G. arborea* ranging from 3.94 (1-year-old) to 53.67 Mg ha⁻¹ (6-year-old). Tree biomass was significantly and positively correlated with PAR_{av}r (0.59) and canopy volume (0.75) which indicated more photosynthetic activity contributing towards tree biomass.

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Table 5. Plant canopy characteristics of different trees

Species	Tree height (m)	Trunk circumference at breast height (cm)	Canopy spread area (m ²)	Average crown volume (m ³)	Height up to first branch (m)
Timber trees					
<i>Albizia procera</i> (Roxb.) Benth	6.3 ± 0.53 ^d	53.0 ± 6.11 ^b	37.59 ± 2.73 ^a	111.1 ± 15.47 ^a	1.9 ± 0.15 ^{de}
<i>Dalbergia latifolia</i> Roxb.	4.9 ± 0.20 ^e	43.3 ± 5.81 ^d	13.53 ± 1.81 ^d	31.7 ± 1.73 ^d	1.3 ± 0.02 ^c
<i>Dalbergia sissoo</i> Roxb.	13.0 ± 0.76 ^a	58.3 ± 3.18 ^b	16.63 ± 1.26 ^c	91.3 ± 5.59 ^b	4.7 ± 0.43 ^a
<i>Gmelina arborea</i> Roxb.	10.2 ± 0.33 ^b	70.3 ± 4.17 ^a	22.07 ± 0.26 ^b	112.3 ± 3.92 ^a	2.5 ± 0.07 ^c
<i>Shorea robusta</i> Gaertn.	7.5 ± 0.41 ^c	49.0 ± 6.65 ^c	9.8 ± 0.98 ^c	65.3 ± 7.21 ^c	3.1 ± 0.63 ^b
<i>Tectona grandis</i> Linn.	6.9 ± 0.13 ^d	46.3 ± 2.40 ^{cd}	14.98 ± 1.48 ^c	39.6 ± 2.12 ^d	3.0 ± 0.13 ^b
Multipurpose tree species (MPTS)					
<i>Acacia catechu</i> (L.f) Willd.	6.3 ± 1.60 ^b	54.6 ± 16.17 ^c	21.4 ± 2.35 ^c	24.6 ± 2.89 ^c	1.6 ± 0.45 ^{ef}
<i>Aegle marmelos</i> (L.) Corrêa.	4.6 ± 0.17 ^c	44.6 ± 6.06 ^d	3.47 ± 0.38 ^e	5.4 ± 0.83 ^{gh}	2.3 ± 0.34 ^c
<i>Azadirachta indica</i> A. Juss.	5.1 ± 0.04 ^d	45.1 ± 4.04 ^d	3.86 ± 0.38 ^{fg}	7.1 ± 1.22 ^e	2.3 ± 0.51 ^c
<i>Emblca officinalis</i> Gaertn.	5.7 ± 0.21 ^{cd}	67.3 ± 7.21 ^b	9.35 ± 0.98 ^d	27.2 ± 1.19 ^c	1.3 ± 0.03 ^e
<i>Leucaena leucocephala</i> (Lam.) de Wit.	9.1 ± 0.17 ^a	47.6 ± 4.48 ^{cd}	27.35 ± 2.25 ^b	119.7 ± 4.74 ^b	2.5 ± 0.27 ^{ab}
<i>Madhuca integrifolia</i> J. F.	5.5 ± 0.23 ^d	40.0 ± 2.64 ^e	4.16 ± 4.72 ^f	10.0 ± 1.15 ⁱ	1.8 ± 0.23 ^c
<i>Melia azedarach</i> L.	9.0 ± 0.76 ^a	96.6 ± 18.76 ^a	40.36 ± 4.55 ^a	167.7 ± 13.21 ^a	2.7 ± 0.27 ^a
<i>Pongamia pinnata</i> (L.) Pierre	4.1 ± 0.32 ^c	23.0 ± 1.15 ^f	1.87 ± 0.15 ^h	2.0 ± 0.27 ^h	2.5 ± 0.15 ^{ab}
<i>Pterocarpus marsupium</i> Roxb.	5.8 ± 0.15 ^c	52.3 ± 1.45 ^c	26.89 ± 2.78 ^b	76.6 ± 2.92 ^c	1.5 ± 0.05 ^f
<i>Sapindus mukorossi</i> Gaertn.	3.5 ± 0.28 ^f	26.3 ± 4.91 ^f	7.80 ± 0.93 ^c	11.3 ± 1.80 ^f	0.8 ± 0.06 ^h
<i>Terminalia arjuna</i> (Roxb. ex DC.) Wight & Arn	6.4 ± 0.30 ^b	53.0 ± 8.14 ^c	17.11 ± 1.53 ^c	49.0 ± 4.31 ^d	2.1 ± 0.10 ^d

Values are represented as mean ± SE. Values having different superscripts within rows are significantly different at $P < 0.05$.

Table 6. Foliar characteristics and light profile of different trees

Species	Leaf area (cm ²)	Leaf area index	Specific leaf fresh wt (mg cm ⁻²)	PAR ($\mu\text{mol cm}^{-1}$) below tree canopy	PAR absorbed/reflected ($\mu\text{mol cm}^{-1}$)
Timber trees					
<i>A. procera</i>	366.70 ± 6.36 ^b	10.54 ± 2.13 ^a	0.19 ± 0.02 ^d	829.16 ± 123.99 ^a	944.07 ± 69.13 ^b
<i>D. latifolia</i>	65.89 ± 1.18 ^d	1.16 ± 0.05 ^c	3.94 ± 0.57 ^c	977.33 ± 66.89 ^a	795.93 ± 51.07 ^c
<i>D. sissoo</i>	58.84 ± 1.18 ^d	0.69 ± 0.11 ^d	4.8 ± 0.67 ^c	316.54 ± 16.67 ^b	1456.67 ± 111.18 ^a
<i>G. arborea</i>	170.80 ± 4.03 ^c	0.53 ± 0.03 ^d	12.0 ± 4.69 ^b	996.08 ± 343.23 ^a	728.70 ± 79.06 ^c
<i>S. robusta</i>	19.39 ± 2.11 ^e	4.16 ± 0.81 ^b	14.71 ± 1.83 ^a	963.31 ± 82.63 ^a	753.64 ± 77.21 ^c
<i>T. grandis</i>	791.91 ± 11.40 ^a	0.64 ± 0.06 ^d	15.35 ± 3.22 ^a	235.76 ± 64.99 ^b	1537.41 ± 128.18 ^a
MPTS					
<i>A. catechu</i>	11.46 ± 2.16 ^c	0.34 ± 0.06 ^f	0.25 ± 0.04 ^h	794.43 ± 78.37 ^{bc}	984.36 ± 99.13 ^b
<i>A. marmelos</i>	131.05 ± 0.81 ^c	2.48 ± 0.36 ^c	3.12 ± 0.27 ^c	243.33 ± 6.68 ^f	1529.81 ± 15.16 ^a
<i>A. indica</i>	180.54 ± 2.5 ^b	7.11 ± 0.78 ^b	0.36 ± 0.03 ^h	873.16 ± 376.65 ^b	900.00 ± 8.14 ^c
<i>E. officinalis</i>	1.80 ± 0.11 ^f	0.27 ± 0.06 ^f	21.17 ± 2.07 ^b	796.08 ± 131.37 ^c	977.04 ± 67.08 ^{cd}
<i>L. leucocephala</i>	70.21 ± 2.34 ^d	1.71 ± 0.14 ^d	0.95 ± 0.15 ^e	588.54 ± 125.04 ^d	1023.70 ± 110.10 ^b
<i>M. integrifolia</i>	62.08 ± 1.43 ^d	0.25 ± 0.01 ^f	47.42 ± 8.41 ^a	1063.23 ± 65.05 ^a	710.00 ± 70.06 ^d
<i>M. azedarach</i>	290.21 ± 4.38 ^a	15.55 ± 4.42 ^a	0.14 ± 0.05 ^h	284.38 ± 36.83 ^e	1535.37 ± 151.15 ^a
<i>P. pinnata</i>	54.89 ± 0.49 ^{de}	0.70 ± 0.01 ^e	8.6 ± 0.66 ^{de}	1192.97 ± 260.05 ^a	580.19 ± 63.04 ^d
<i>P. marsupium</i>	199.91 ± 2.85 ^b	8.32 ± 1.86 ^b	2.32 ± 0.21 ^f	1033.17 ± 105.34 ^a	740.00 ± 81.06 ^d
<i>S. mukorossi</i>	29.66 ± 1.27 ^c	0.33 ± 0.05 ^f	14.3 ± 1.57 ^c	1102.54 ± 136.44 ^a	670.56 ± 53.05 ^c
<i>T. arjuna</i>	55.74 ± 0.43 ^d	0.33 ± 0.09 ^f	9.29 ± 1.49 ^d	377.67 ± 127.25 ^c	1395.56 ± 128.16 ^{ab}

Values are represented as mean ± SE. Values having different superscripts within rows are significantly different at $P < 0.05$.

Significant variation in soil properties was recorded for different trees (Table 8). Although the soil pH at 0–15 cm depth did not vary significantly, at 15–30 cm depth it was significantly higher than that in controlled condition under *M. azedarach*, *D. sissoo*, *T. grandis*, *A. procera*, *M. integrifolia*, *T. arjuna*, *P. pinnata*, *G. arborea*, *L. leucocephala*, *S. robusta*. Imayavarambar *et al.*²³ and Oraon *et al.*⁹ also reported improving trend of soil pH under different agroforestry species. With respect to elec-

trical conductivity, significant decrease at 0–15 cm was recorded for *A. indica* and the value did not change significantly for *T. arjuna*, *E. officinalis*, *P. pinnata*, *G. arborea*, *L. leucocephala* and *S. robusta*. At 15–30 cm soil depth, maximum EC was recorded for *D. sissoo* which was at par with that of *M. azedarach*. The soil organic carbon did not change significantly for different species. With respect to available N, the value at 0–15 cm depth decreased significantly for *T. grandis*, *D. latifolia*

Table 7. Species-wise tree biomass accumulation in different trees (simulated over 20 years using CO2FIX model)

Species	Tree biomass (above and below ground) Mg DM ha ⁻¹	
	Base line	Simulated
Slow growing		
<i>A. indica</i>	49.54	142.53
<i>M. integrifolia</i>	57.90	150.89
<i>P. pinnata</i>	46.94	139.93
<i>S. mukorossi</i>	41.92	134.91
Medium growing		
<i>A. marmelos</i>	143.07	384.51
<i>A. procera</i>	141.09	382.53
<i>D. latifolia</i>	141.09	382.53
<i>S. robusta</i>	136.42	363.90
<i>E. officinalis</i>	130.07	361.00
<i>P. marsupium</i>	145.05	386.49
<i>T. grandis</i>	137.29	378.72
<i>T. arjuna</i>	149.16	390.60
<i>A. catechu</i>	121.36	342.18
Fast growing		
<i>D. sissoo</i>	172.47	450.88
<i>G. arborea</i>	190.98	469.39
<i>L. leucocephala</i>	172.47	450.88
<i>M. azedarach</i>	168.30	446.71

Table 8. Soil properties under different trees

Species	pH		EC		Available N		Available K ₂ O	
	0–15 cm depth	15–30 cm depth	0–15 cm depth	15–30 cm depth	0–15 cm depth	15–30 cm depth	0–15 cm depth	15–30 cm depth
<i>A. marmelos</i>	5.53 ± 0.29 ^a	5.32 ± 0.16 ^b	0.06 ± 0.005 ^a	0.07 ± 0.01 ^b	406.9 ± 26.1 ^a	427.4 ± 45.9 ^a	182.4 ± 22.1 ^b	265.6 ± 86.5 ^a
<i>A. procera</i>	5.53 ± 0.24 ^a	5.58 ± 0.22 ^a	0.08 ± 0.006 ^a	0.07 ± 0.020 ^b	418.1 ± 22.0 ^a	472.3 ± 19.7 ^a	275.2 ± 53.2 ^a	212.8 ± 33.3 ^b
<i>A. indica</i>	5.20 ± 0.09 ^a	5.27 ± 0.09 ^b	0.01 ± 0.003 ^d	0.02 ± 0.001 ^d	434.9 ± 7.4 ^a	389.2 ± 33.9 ^a	267.2 ± 47.1 ^a	297.6 ± 8.3 ^a
<i>D. latifolia</i>	5.49 ± 0.13 ^a	5.21 ± 0.41 ^b	0.05 ± 0.011 ^b	0.03 ± 0.01 ^c	364.0 ± 17.1 ^b	352.8 ± 14.1 ^a	145.6 ± 10.5 ^b	144.0 ± 9.9 ^b
<i>D. sissoo</i>	5.59 ± 0.35 ^a	5.47 ± 0.01 ^a	0.07 ± 0.017 ^a	0.12 ± 0.020 ^a	399.4 ± 11.3 ^a	380.8 ± 29.1 ^a	164.8 ± 23.9 ^b	187.2 ± 2.7 ^b
<i>E. officinalis</i>	5.12 ± 0.09 ^a	5.20 ± 0.07 ^b	0.02 ± 0.001 ^c	0.02 ± 0.001 ^d	390.1 ± 22.0 ^a	358.4 ± 8.5 ^a	267.2 ± 14.2 ^a	281.6 ± 5.7 ^a
<i>G. arborea</i>	5.48 ± 0.20 ^a	5.65 ± 0.16 ^a	0.02 ± 0.003 ^c	0.02 ± 0.001 ^d	401.3 ± 9.3 ^a	380.8 ± 28.7 ^a	387.4 ± 31.2 ^a	294.4 ± 61.0 ^a
<i>L. leucocephala</i>	5.56 ± 0.09 ^a	5.69 ± 0.15 ^a	0.02 ± 0.003 ^c	0.02 ± 0.003 ^d	423.7 ± 26.1 ^a	405.1 ± 27.1 ^a	302.4 ± 84.9 ^a	254.4 ± 49.9 ^a
<i>M. integrifolia</i>	5.07 ± 0.04 ^a	5.53 ± 0.23 ^a	0.05 ± 0.005 ^b	0.05 ± 0.004 ^c	402.5 ± 23.4 ^a	417.2 ± 11.3 ^a	156.8 ± 16.2 ^b	168.0 ± 30.5 ^b
<i>M. azedarach</i>	5.84 ± 0.56 ^a	6.15 ± 0.43 ^a	0.07 ± 0.020 ^a	0.09 ± 0.035 ^a	293.0 ± 33.2 ^c	393.8 ± 19.7 ^a	177.6 ± 45.6 ^b	305.6 ± 79.6 ^a
<i>P. pinnata</i>	5.09 ± 0.02 ^a	5.55 ± 0.02 ^a	0.02 ± 0.002 ^c	0.02 ± 0.001 ^d	386.4 ± 25.8 ^a	389.2 ± 4.8 ^a	360.0 ± 5.5 ^a	367.2 ± 37.4 ^a
<i>P. marsupium</i>	5.19 ± 0.09 ^a	5.28 ± 0.08 ^b	0.02 ± 0.001 ^c	0.02 ± 0.001 ^d	379.1 ± 23.38 ^a	395.6 ± 24.4 ^a	220.5 ± 34.3 ^b	231.2 ± 36.0 ^b
<i>S. mukorossi</i>	5.19 ± 0.03 ^a	5.34 ± 0.02 ^b	0.05 ± 0.005 ^b	0.04 ± 0.008 ^c	431.2 ± 3.2 ^a	438.6 ± 32.4 ^a	192.0 ± 30.5 ^b	177.6 ± 26.7 ^b
<i>S. robusta</i>	5.02 ± 0.01 ^a	5.67 ± 0.09 ^a	0.02 ± 0.002 ^c	0.01 ± 0.001 ^d	400.4 ± 1.6 ^a	417.2 ± 24.2 ^a	218.4 ± 34.6 ^b	235.2 ± 5.5 ^b
<i>T. grandis</i>	5.39 ± 0.14 ^a	5.48 ± 0.09 ^a	0.04 ± 0.01 ^b	0.05 ± 0.014 ^c	368.1 ± 29.5 ^b	459.2 ± 25.2 ^a	171.4 ± 20.2 ^b	180.8 ± 20.8 ^b
<i>T. arjuna</i>	5.47 ± 0.07 ^a	5.55 ± 0.05 ^a	0.02 ± 0.003 ^c	0.02 ± 0.003 ^d	382.6 ± 21.0 ^a	429.3 ± 31.9 ^a	288.0 ± 93.6 ^a	337.6 ± 34.2 ^a
Fallow	5.32 ± 0.12 ^a	5.30 ± 0.01 ^b	0.03 ± 0.003 ^c	0.02 ± 0.003 ^d	388.2 ± 29.3 ^a	375.2 ± 19.4 ^a	276.8 ± 15.2 ^a	276.0 ± 29.1 ^a

Values are represented as mean ± SE. Values having different superscripts within rows are significantly different at $P < 0.05$.

and *M. azedarach*. However, at 15–30 cm depth, no significant change in available N was recorded. The available P content also did not change significantly at both the soil depths. In case of available K, significant reduction than the fallow was recorded at 0–15 cm soil depth for *A. marmelos*, *M. azedarach*, *D. latifolia*, *D. sissoo*, *T. grandis*, *M. integrifolia* and *S. mukorossi*. At 15–30 cm depth, value reduction was recorded for *D. latifolia*, *D. sissoo*,

T. grandis, *M. integrifolia* and *S. mukorossi*. Shepherd *et al.*⁸ found that agroforestry systems did not significantly reduce N deficits except when a high proportion of the total biomass was returned to the soil, rather than removed from the farm. Although agroforestry increased N input through biological N fixation and deep N uptake, this was offset by a larger nutrient removal from the farm in harvested products. Hence, reduction in the available N

and K content in the soil in our study can be attributed to higher uptake by the species and variation in soil depth can be attributed to variation in feeder root distribution among the species. This warrants additional nutrient supplementation for acid soils of eastern plateau and hill conditions of India for maintaining soil fertility on a long-term basis.

Conclusion

This article aimed at characterizing the different tree-based (i.e. timber trees and MPTs) agroforestry systems considering the tree canopy and plant growth and development parameters. The study clearly indicated higher biomass production potential of *G. arborea*, *D. sissoo* and *L. leucocephala* in Jharkhand. The study also showed higher PAR below tree canopy for *P. pinnata*, *A. catechu*, *P. marsupium*, *M. integrifolia*, *A. indica*, *S. mukorossi*, *E. officinalis*, *G. arborea*, *D. latifolia* and *A. procera* indicating their compatibility with majority of the agricultural crops. Finally there is a need for replenishment of nutrients in the soil for long-term sustainability of soil fertility in agroforestry systems.

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