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Assessment of eighteen years old plantation of *Azadirachta indica* for biomass, nutrient accumulation and soil improvement in Entisols of Chhattisgarh, India

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Abstract

Azadirachta indica was grown at 3 m x 3 m spacing in the upland of red lateritic soil in Chhattisgarh plain. The selected felling was made at 18 years of age to estimate the accumulation of biomass along with quantity of nitrogen, phosphorus, potassium and carbon stored in different component of trees. The survival rate of plantation was 45.05 percent from six years of plantations. After felling, all the tree components *viz;* bole, branch, twigs, foliage were separated manually, while main and lateral roots were dig out carefully after lightly moistened soil till the last end. Fresh weights of each component were recorded and dry weights were estimated by drying subsamples at 75° C in hot air oven. The growth rate in height, CD and DBH was 41.0, 1.25 and 0.99 cm, respectively up to 6 yrs while it was 24.0, 0.99 and 0.53 cm between 6 to 12 years growth period and 51.0, 0.43 and 0.76 cm, respectively between 12 to 18 years of growth period, where the total growth in height, CD and DBH was 7.43 m, 6.75 cm and 13.75 cm, respectively. The dry matter production for bole wood, bole bark, branch, twigs, foliage and root were found 28.86, 4.34, 22.70, 2.87, 3.31 and 18.78 kg tree^{-1}, respectively with percentage share of biomass production was in the order of bole wood > branch > root > bole bark > foliage > twigs. The per tree total harvesting of NPK was found 267.15N, 74.7P and 1475.74K g tree^{-1} of above ground part while 93.9 g N, 12.46 g P and 559.6 g K was stored in below ground root parts, where C was sequestered 25.75 and 7.45 kg tree^{-1} in above and below ground parts, respectively of a tree. The improvement of soil condition under *A. indica* over 18 yrs of plantation showed decline in pH by 2.52% toward acidic portfolio, while WHC, organic carbon and available NPK were increased by 13.52, 57.63, 61.35, 172.10 and 16.13%, respectively as compared to adjacent open barren land.

Keywords: *Azadirachta indica,* Biomass, Growth, Nutrients, Soil amelioration

Introduction

Out of the India's total 329 million hectare geographical area, 114.01 m ha (34.7%) land suffers from various kinds of degradation problems (Trivedi, 2010). Ravine, shallow gravely red soils and rocky areas of semi-arid region, hot desert and sand dunes lands etc. comes under wastelands in the tropical world, where the shortage of wood for fuel, household use and raw material for paper industries are increasing ever increasing human and livestock population, which has put enormous pressure on the forest, resulting the reduction in forest cover less than to a minimum requirement. Therefore, it is an important issue to take care to manage eco-resources for conserving environment and natural resource cycling with the management of fast growing multipurpose tree species (MPTS) on degraded land ecosystem or wasteland (Roy, 2016) to provide around 10 to 20 t ha^{-1} year^{-1} of dry matter to full fill the demand of local communities.

Neem (*Azadirachta indica* A. Juss.) is well known indigenous MPTS of Indian sub-continent for obtaining fuel and timber wood, fatty oil, gum and insecticide/ pesticide, bio-fertilizers and cosmetics, etc (Bijalwan *et al.,* 2017). As fodder the neem leaves are also relished by the animals and it contains 12-20% protein, 22.9% carbohydrates, moderate NDF-ADF (10-15%) contents, several fatty acids, liminoids and minerals with vitamin-C, carotene etc. Even after the extraction of oil from seeds, the available neem cake is also used as supplementary feed to milch animals and poultry (Heuze *et al.,* 2015). Looking to its potential it is extensively planted for rehabilitation of degraded ecosystems and wastelands in arid and semi-arid regions and observed as is highly efficient in restoring soil productivity and improving environment (Tiwari, 1992). The present study was aimed at exploring the potentiality of the *Azadirachta indica* on red lateritic soils (Bhata lands) in central India under rainfed condition.

Materials and Methods

Study site: The present study was conducted on 18 years (*2011-12)* old plantation of *Azadirachta indica* which was planted at 3 x 3 m spacing in red lateritic soil (Entisols) in one hectare area at IGKV, Research Farm, Baronda (Raipur), Chhattisgarh. The climate of study site was found dry humid sub-tropical with an average annual rainfall of 1250 mm, where 80 percent was received during June to mid August. The mean monthly maximum temperature varied from 13.2 ^{0}C in December to 28.3 ^{0}C in May. The maximum temperature went beyond 45 ^{0}C in May and minimum went below 10 ^{0}C in December. The relative humidity varied between 70-90% from mid June to March end. Sunshine period in a day prolonged more than 9 hours in summer and less than 7 hours in winter. Evaporation remained high during April to June (10-13 mm day $^{-1}$) and low during July to February (2.4-5.0 mm day $^{-1}$).

Experimental designing: The area was divided into three strips for the study of plantation performance in regard to survival, growth, biomass and nutrient accumulation as well as soil improvement. The populations of tree stands were measured for growth in height, collar diameter (CD) and diameter at breast height (DBH) and mean of population to select the representative stands of trees in three groups in three strips for felling, which were made with the help of hand saw at 10 cm above the ground level (Chaturvedi and Khanna, 1982). After felling, trees were measured for total tree height, bole height, clear bole height and DBH and all the tree components *viz;* bole, branch, twigs, foliage were separated manually, while main and lateral roots were dig out carefully after lightly moistened soil till the last end. Fresh weight of each component was recorded, while the dry weight was estimated by drying sub-samples at 75^o C in hot air oven. All the tree components were further analyzed for nutrients *viz.,* N, P, K and C content (AOAC*,* 1975; Negi *et al*., 2003).

Sampling and analyses: Soil samples were collected from under trees and from adjacent open field (control/ area without tree) at the depth of 0-15 cm, 15-30 cm, 30-60 cm and 60-100 cm with the help of soil agar. Bulk samples were used for analysis of water holding capacity (WHC), pH, organic carbon, available nitrogen, phosphorus and potassium as per the standard methods of Jackson, (1967) and (AOAC*,* 1975). Standard deviation was worked out for growth, biomass and nutrients data, while ANOVA was applied for soil nutrients data.

Results and Discussion

Tree growth characteristics: The morphological characteristics of *A. indica* grown as block plantation in red lateritic soil showed that total height of eighteen years old trees was 7.43 ± 0.86 m with bole height of 4.24 ± 0.52 m sequentially (Table 1). The collar diameter (CD) was recorded as 16.75 ± 0.69 cm with DBH of 13.75 ± 1.29 cm. The survival rate of population was 45.05% at six years of growth and it almost remained same till 18th years of growth. The mean annual increment in tree growth for height, collar diameter and diameter at breast height was 41.0, 1.25 and 0.99 cm, respectively per year up to six years and during 6 to 12 years growth phase it was 24.0, 0.99 and 0.53 cm, respectively, while during 12 to 18 years growth phase it was 51.0, 0.43 and 0.76 cm, respectively. All the trees had moderate to large crown spread when they were grown either as sole tree or as wider spacing plantation, but when grown at 3 x 3 m spacing for more than 18 years, the crown growth were restricted due to close proximity of stands. Rai *et al.* (2000) observed that crown spread in 12 MPTs was related to branching pattern of species and space available around within the growth period. The growth performance of trees is influenced by their genetic potentialities as well as adaptabilities to the edaphic and climatic conditions; here in red lateritic soil the over all, growth performance was comparatively poor in *A. indica.* Naugraiya and Puri (2001) also reported that growth behavior of a tree was associated with the potential adoptability in particular environment and soil.

Table 1. Morphological features of 18 years old *A.indica* plantation in Entisols

Growth parameters	Mean
Total height (m)	7.43 ±0.86
Bole height (m)	4.24 ±0.52
Clear bole height (m)	2.01 ±0.34
Crown length (m)	5.41 ±0.65
Crown diameter (m)	3.90 ±0.43
CD (cm)	16.75 ±0.69
DBH (cm)	13.75 ±0.25
No. of branches (n)	8.50 ±1.29

Tree biomass and nutrients accumulation: Selected stands of trees were harvested for accumulation of biomass (dry matter) in different components like bole wood, bole bark, branches, twigs, foliage and roots aggregating 62.07 ± 5.65 kg tree^{-1} total above ground biomass (Table 2), while root dry matter was 18.78 ± 2.25 kg tree^{-1} thus over all total dry matter of harvested tree stand was 80.85 ± 7.09 kg tree^{-1}. The percentage dry matter of the tree shared by different components was in

Table 2. Biomass and nutrient accumulation in 18 years old *A.indica* plantation in Entisols

Attributes	Component of trees							
	Bole	Bark	Branch	Twig	Leaves	AGB	Root	Total
Dry weight(kg tree^{-1})	28.86	4.34	22.7	2.87	3.31	62.07	18.78	80.85
	±2.92	±0.44	±2.98	±0.70	±0.71	±5.65	±2.25	±7.09
Nitrogen(kg tree^{-1})	83.68	19.07	122.59	18.67	23.14	267.15	93.9±	361.05
	±8.48	±1.93	±16.11	±4.54	±4.94	±11.23	11.23	±30.64
Phosphorus(kg tree^{-1})	41.84	3.43	21.34	3.1±	4.99	74.7	12.46	87.09
	±4.24	±0.35	±2.80	0.75	±1.06	±1.48	±1.48	±7.62
Potassium(kg tree^{-1})	383.77	48.99	740.1±	126.39	176.49	1475.7	559.64	2035.4
	±38.89	±4.97	97.24	±30.75	±37.68	±66.91	±66.91	±167.19
Carbon(kg tree^{-1})	13.03	1.53	9.03	1.06	1.10	25.75	7.45	33.20
	±1.32	±0.16	±1.19	±0.26	±0.23	±2.38	±0.89	±2.95

the order of bole wood (35.7) > branch (28.1)> root (23.2) > bole bark (5.4) > foliage (4.1) > twigs (3.5). Singh *et al.* (2005) recorded similar trend of biomass distribution in exotic *E. tereticornis* when grown for short rotation crop in sub-humid dry tropical environment. Naugraiya *et al.* (2005) also observed similar trend in case of one decade old non-leguminous species grown in Entisols.

The total quantity of nutrients *viz.,* N, P and K available in the tree was 361.05, 87.09 and 2035.38 g tree^{-1} with underground root share of 26.3, 14.3 and 27.5%, respectively. The accumulation of nutrients in different components of *A. indica* was in order of branches < bole wood < foliages < bole bark < twigs for nitrogen; bole wood < branches < foliages < bole bark < twigs for phosphorus and branches < bole wood < foliages < twigs < bole bark for potash.

The storage of carbon was estimated from ash contents of each tree component of *A.indica* and it aggregated to a total of 33.20 kg C tree^{-1} which was shared by 25.75 and 7.45 kg C tree^{-1} in above and below ground parts, respectively at the age of 18 years growth, while in above ground portion of tree, 50.6% carbon was shared by bole-wood followed by branches (35.1%), and the accumulation of carbon in twigs, foliages and bole bark was less than 15%, almost in equal ratio. Mohamed *et al.* (2016) also observed more or less similar trend in carbon accumulation of *A. indica* and *Simarouba glauca*.

Rao *et al.* (2000) worked out the biomass and nutrient accumulation behavior in MPTs with similar findings, which indicated that highest nutrient concentration was in foliage as compared to woody parts of trees and minimum in bole wood and bole bark. Similar trend in nutrient concentration was also reported in MPTs growing in Entisols by Naugraiya *et al.* (2005). Thus the removals or harvesting of trees are directly and indirectly respons--ible for removal of all kinds of nutrients, carbon and stored energy from site of plantation where they were grown. Thus variation in removal of N, P, K and C through different parts of tree, where these were stored up to the growth of 18 years was recorded; however some parts of branches, twigs and foliage get deposited on the ground after falling and decomposition to enrich the soil profile.

Tropical forest plantations are increasingly becoming important because of their ability to enhance biomass/ carbon resources in an area (FAO, 2006) and improve degraded soil organic matter (Naugraiya and Puri, 1994; Wang *et al*., 2010). Fast-growing tree species are generally considered to accumulate soil nutrients faster than slow-growing ones when multiple rotations are implemented. Inagaki and Tange (2014) analysed the nutrient accumulation in tropical trees growing in infertile soils, where P use efficiency was more affected by soil conditions than N use efficiency and the differences in the tree groups as well as genetic differences affected the use efficiency of both the nutrients Both N and P are major nutrients for tree growth, however, they differ in their sources, site availability, metabolic forms and degrees of translocation in plant organs and result of which, they might not accumulate in aboveground biomass in the same way. Thus the difference in degree of structural dependency on these nutrients should be taken into account when assessing the accumulation of nutrients and total aboveground biomass in plants.

***Physico-chemical changes in soil*:** Soil of any plantation site gets changed over a period based on utilization and storage of nutrients by the tree itself where some portion of nutrients get deposited into soil after falling and decomposition of litters. The water holding capacity (WHC) revealed the availability of hydrophilic organic material in the soil to bind the water molecules was maximum under plantation (38.34 to 55.07%) and

Table 3. Status of soil characteristics under 18 years old *A .indica* plantation in Entisols

Soil	pH	WHC (%)	Organic C (%)	Available N (kg ha^{-1})	Available K (kg ha^{-1})	Available P (kg ha^{-1})
Site						
A. indica	6.1	47.18	0.8	233.32	18.45	130.32
Open	5.95	41.78	0.51	144.78	6.79	118.8
CD (P<0.05)	**0.15**	**3.12**	**0.07**	**23.35**	**1.53**	**14.62**
Soil depth (cm)						
0 -25	6.53	35.43	0.83	216.91	16.33	151.39
25-50	6.08	41.25	0.73	204.37	13.90	124.12
50-75	5.80	47.98	0.60	179.70	10.91	113.52
75-100	5.69	53.27	0.48	155.23	9.34	94.21
CD (P<0.05)	**0.09**	**1.80**	**0.04**	**13.48**	**0.88**	**8.44**
Interaction						
A.i. x 0 -25	6.61	38.36	1.02	262.38	23.53	170.01
A.i. x 25-50	6.1	43.8	0.86	256.11	21.37	131.3
A.i. x 50-75	5.85	51.5	0.73	226.64	15.6	123.68
A.i. x 75-100	5.82	55.07	0.6	188.16	13.29	96.28
Open x 0 -25	6.45	32.5	0.64	171.44	9.13	132.76
Open x 25-50	6.05	38.7	0.59	152.62	6.42	116.93
Open x 50-75	5.74	44.45	0.46	132.76	6.22	103.35
Open x 75-100	5.55	51.46	0.36	122.3	5.38	92.14
CD (P<0.05)	**0.06**	**1.18**	**0.03**	**8.83**	**0.58**	**5.53**

A.i.: *Azadirachta indica*

minimum under control plot (32.5 to 51.46%) at 0-15 cm and 60-100 cm depth, respectively with sharp significant variation at different layer of depth and it increased with increasing the soil depth (Table 3). The concentration of H^+ ions in the soil media decides the nature of soil, which directly/ indirectly responsible for ultimate growth and performance of plant grown. It was evident from the data that highest acidic pH value was observed at surface layer (0-15 cm) which further became more acidic with increasing the soil depth (60-100 cm). Organic carbon is considered as a basic parameter for determining the soil quality, because the availability of organic substances in its bio-degradable forms is found to be responsible to build a rich humus soil. There was sharp variation in availability of organic carbon at different soil depth where it was maximum at surface layer (1.02%) followed by 15-30 cm soil depth (0.86%) and gradually decreased upto 100 cm depth (0.60%) under tree as well as in open field. It was maximum at 0-15 cm top layer (064%) and minimum at 60-100 cm depth (0.36%).

The soil depth significantly influenced the amount of availability of macro-nutrients, where these were recorded maximum at top layer of soil (0 -15 cm) and gradually decreased as the soil depth increased (60-100 cm), where under the *A.indica* plantations organic carbon, nitrogen, phosphorus and potassium were ran--ged 0.60 to 1.02%, 262.38 to 188.16, 23.26 to 13.29 and 170.01 to 96.28 kg ha^{-1}, respectively. Thus enhancement of the quantity of organic carbon, N, P and K in the soil under tree as compared to the adjacent open barren land was 57.63, 61.35, 172.1 and 16.13, respectively. This improvement was varied for each parameters at every depth slots, where pH and Organic carbon showed similar pattern of soil change in order of 60-100 cm < 0-15cm < 30-60 cm < 15-30c m soil depth, while WHC and potassium showed similar pattern of change in order of 15-30 cm < 30-60 cm < 0-15 cm < 60-100 cm. However improvement in concentration of N and P was quite varied and it was observed in order of 30-60 cm < 15-30 cm<60-100 cm <0-15 cm for nitrogen and 15-30 cm < 0-15 cm < 30-60c m < 60-100 cm for phosphorus. The decrease in availability of nutrients with increasing soil depth is common feature in degraded soil, the availability of comparatively more nutrients under tree crop, could be attributed to the role of tree for conducing the micro-climate status for rapid decomposition of litter and it attributed to solubilizing behavior of organic acids, which ever released into soil (Rao *et al.,* 2000). Similar trend was also seen under high density plantation of *E. tereticornis* (Naugraiya *et al*., 2008)*, L. leucocephala, (*Naugraiya and Sisodiya, 2011), *D.sissoo, (*Naugraiya and Sisodiya, 2015) and *G. arborea* (Naugraiya and Shaw, 2014), where the significant variation was seen under different tree species at both the layers of soil *i.e.* surface and lower depths of soil, as nutrients status of soil decreased with increase in soil depth, could be attributed to deep rooted nature of tree, which exerted on nutrient absorption from deep layer of soil (Bhardwaj *et al.,* 2001). However, the higher quantity of NPK on the surface layer of soil was also attributed to tree plantations for long period which prevented leaching down the nutrients from the surface during rainy season, resulting higher values at the surface of the soil than at lower soil depths.

Conclusion

Performance of *Azadirachta indica* plantation in poor soil like Entisols in humid tropic agro-climatic region, was not good, but the improvement of soil condition over 18 years of tree growth was found significant with decline in pH by 2.52% toward acidic portfolio, where there was subsequent increment in water holding capacity, organic carbon and available N, P, K by 13.52, 57.63, 61.35, 172.10 and 16.13%, respectively as compared to adjacent open barren land.

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