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Acacia nilotica-based traditional agroforestry system: effect on paddy crop and management

S. S. Bargali[1,*], Kiran Bargali[2], Lalji Singh[1], Lekha Ghosh[1] and M. L. Lakhera[3]

[1]Department of Forestry, and
[3]Department of Statistics and Computer Science,
College of Agriculture, Indira Gandhi Agricultural University,
Raipur 492 006, India
[2]Department of Botany, Kumaun University, Nainital 263 002, India

A study was conducted in an age series of *Acacia nilotica* (L.) Willd. ex Del (6–28 years old)-based traditional agroforestry system in the sub-humid region of Chhattisgarh. The effects of this tree on different rice (*Oryza sativa*) crop parameters (plant density, plant height, effective tillers, total aboveground biomass and grain yield) under natural conditions (without any management practices in trees) and under tree management conditions (cutting of 10% of basal tree branches) were evaluated. The growth and productivity parameters were taken in three directions (a central line passing from the centre of the tree bole, and right

*For correspondence. (e-mail: surendrakiran@rediffmail.com)

and left to this central straight line) and at four distances (1, 3, 5 and 7 m from the tree base). The impact of the tree on the crop was maximum at 1 m distance from the tree trunk. The data were also compared with different crop parameters in the open field (beyond the reach of the tree canopy). With increase in tree age, crown diameter and diameter at breast height (DBH), rice productivity reduced from 4.7 (under 9-yr-old tree) to 28.8% (under 28-yr-old tree). Whereas under 6-yr-old tree, there was an increase (4%) in grain yield. With increase in tree canopy size the plant density and effective tillers also reduced. Per cent yield reduction showed significant positive correlation with tree age, crown diameter and DBH. After the removal of 10% of basal tree branches (in 12–28-yr-old trees), the crown diameter of trees was reduced (0.81–3.77%), plant density (0.05–1%), effective tillers (1.19–5.8%) and grain yield (1.52–2.92%) increased significantly and plant height decreased (0.09–1.32%) over the unmanaged (without cutting the tree branches) condition.

Keywords: *Acacia nilotica*, crown diameter, rice, traditional agroforestry, tree age.

IN Chhattisgarh, rice (*Oryza sativa*) is a main crop and is cultivated on 3.5 mha area, which is about 81% area of agricultural land in the rice season. This crop is grown mostly under rainfed conditions (about 85%) and about 8–10% of the rice area comes under huge bunds[1]. Generally, new bunds (having 1.5 m width and height around the paddy fields) are used for growing upland crops for one or two years. Subsequently, these bunds are left fallow and are inhabited by naturally growing tree species. In the Chhattisgarh plains, the naturally growing trees on bunds and boundaries form an important traditional agroforestry system, dominated by *Acacia nilotica*, *Terminalia tomentosa*, *Albizia procera*, *Butea monosperma* and *Tectona grandis*[2]. *A. nilotica* (L.) Willd. ex Del, commonly known as babool, is a multipurpose nitrogen-fixing legume. Being a hardy legume tree, *A. nilotica* survives for a longer time and is the most preferred species in the traditional agroforestry system of the area because it provides fuel, fodder, small timber, wood for agricultural implements, local medicines and gums, but reduces crop yield[2–4]. In addition, its nitrogen-fixing ability and enhancement in organic matter makes it one of the most preferred species in rice bunds. The role of trees in maintaining and improving soil productivity is considered central to the sustainability of many agroforestry systems. The beneficial influences of tree-based cropping systems on increasing soil organic matter, improving soil fertility build-up and restoring soil physical conditions are well recognized[5,6]. Improvement in water-holding capacity and soil structure along with several fold increase of nitrogen and organic carbon content in the soil under trees than fallow has already been reported[7]. As an old traditional practice, farmers do not follow canopy management of the trees; rather they cut

and sell trees that are more than 20 years old. Crop yields are reported to increase when trees are cut or coppiced in agroforestry[4,8,9]. The main objectives of the present study were to analyse the effect of (1) tree age, (2) distance from the tree trunk, (3) tree crown cover and (4) 10% removal of basal tree branches of *A. nilotica* trees on the growth and productivity of paddy (*Oryza sativa*, variety IR-64, Broadcasted) crop.

The study was carried out in rice bunds of the villages Malood, Hasda and Parastarai, District Durg (20°23′–22°02′N lat., 80°46′–81°58′E long.), Chhattisgarh plains, India (Figure 1). *A. nilotica* grows naturally in bunds at irregular spacing. Soils of all the sites are residual, vertisol, brown to black in colour, and clay to clay loam in texture. The soil swells upon wetting. However, during the dry summer season it shrinks causing deep wide cracks. Soils are poor to moderate in nutrients[10,11]. Different soil characteristics are given in Table 1. The climate is monsoonal, sub-humid, tropical and is characterized by marked seasonality. The year is divisible into three seasons: rainy (mid-June–September), winter (November–January) and summer (February–mid-June). October is the transition month between rainy and winter seasons. Mean monthly maximum temperature varies from 25°C in January to 40°C in May, and mean monthly minimum from 11°C in January to 27°C in June. The mean annual rainfall is about 1286 mm, of which about 86.9% occurs during the rainy season due to the southwest monsoon. Mean monthly relative humidity ranged from 39 to 84%, and was maximum during August and minimum during May.

The potential natural vegetation of the study area is distributed in patches and is dominated by *A. nilotica*, having an average density of 20–25 trees ha^{-1} and 70–80 trees ha^{-1} across the sites and on bunds respectively[2]. Size of the rice field varies from 0.25 to 0.5 ha. In the agricultural fields mostly rice (*Oryza sativa*) is sown during the rainy season. Soil tillage practices as well as management operations are the same under and outside the tree canopy. After the rice crop the fields mostly remain fallow for the rest of the year and are subjected to grazing by domestic animals from the villages in a radius of 1.5–2.5 km.

Eight rice fields (0.25–0.50 ha size) with similar cultural practices were selected having *A. nilotica* trees on bunds of different ages (6, 9, 12, 15, 18, 20, 22, 28 years

Table 1. Different soil characteristics (0–30 cm depth) under *Acacia nilotica*-based traditional agroforestry systems (after Pandey *et al.*[10])

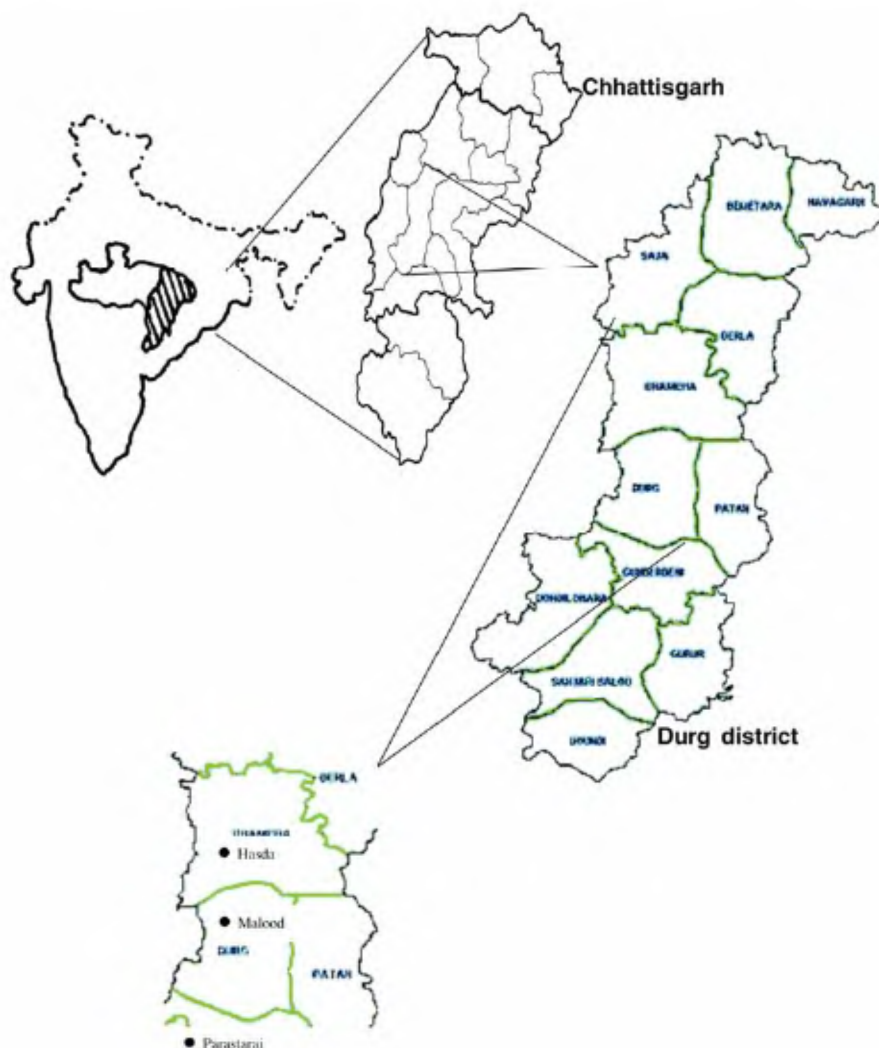| Soil characteristics	Mid-canopy	Canopy edge	Canopy gap
Sand particles (%)	36.78	37.20	41.02
Silt particles (%)	21.20	21.40	21.68
Clay particles (%)	42.02	41.40	37.30
Soil pH	6.58	6.96	7.13
Organic carbon (%)	0.98	0.83	0.61
Total N (%)	0.085	0.065	0.038
Total P (%)	0.065	0.064	0.062

Figure 1. Location map of the study area.

Table 2. Characteristics of *A. nilotica* across rice fields

Tree age (yrs)	Crown diameter (m)	DBH (cm)	Crown diameter after removal of 10% of basal branches (m)
6	5.9	18	–
9	8.3	22	–
12	8.5	29	8.3
15	9.3	36	9.1
18	10.6	38	10.2
20	11.4	41	11.3
22	11.9	42.5	11.8
28	12.3	43.2	12.2

old) and marked. The diameter at breast height (DBH) and crown diameter of three trees of each age group were measured. One tree from each age group was marked separately and 10% of its lower branches were cut (the total branches of the trees were counted and one-tenth of these branches was removed from the base), to observe

the effect on crop yield. Three radial transects were laid under each tree at random along which the crop was sampled at 1 m, 3 m, 5 m and 7 m distance from the tree trunk. The open area at 12 m from the tree trunk was treated as control field.

For each crop sample, plant density (number of clumps), plant height and number of effective tillers were recorded in 1 × 1 m quadrat. The plants were harvested and dried in an oven at 80°C to constant weight and weighed to determine the grain yield and straw yield. Regression analyses and ANOVA were used to develop a relationship between age of the trees and different parameters of the paddy crop.

The DBH of *A. nilotica* across the paddy crop fields was 18 cm for 6-yr-old tree and increased up to 32 cm for 28-yr-old tree (Table 2). The crown diameter ranged from 5.9 to 12.3 m. Crown diameter and DBH showed significant positive correlation with the age of the tree ($r = 0.960$ and 0.943 respectively).
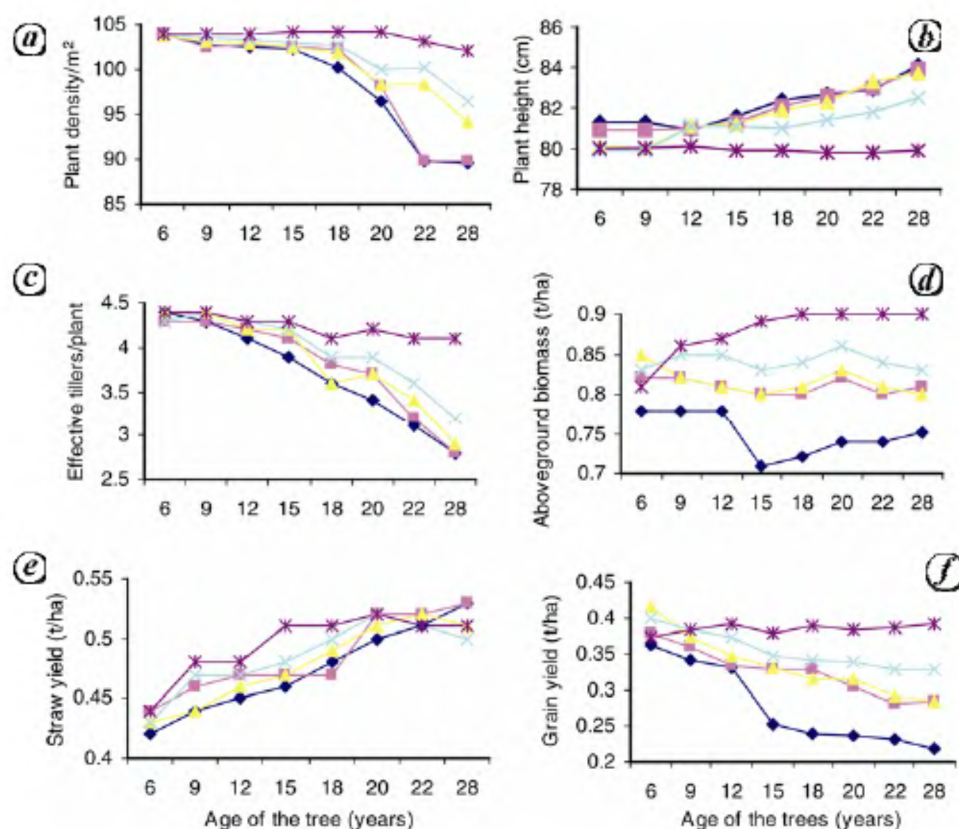
Figure 2. Mean values of different crop parameters across rice fields. *a*, Density; *b*, Plant height; *c*, Effective tillers; *d*, Total aboveground biomass; *e*, Straw yield and *f*, Grain yield measured at different distances from *Acacia nilotica* trees. ━◆━, 1 m distance; ━■━, 3 m distance; ━▲━, 5 m distance; ━✕━, 7 m distance and ━✳━, open field.

Table 3. Regression equation and correlation coefficient for per cent reduction/increase in different parameters (*y*) of rice crop vs tree age (*x*)

Regression equation	Correlation coefficient (*r*)
Plant density; $y = -25.197 + 1.777x$	0.630*
Effective tillers; $y = -67.477 + 4.752x$	0.949**
Aboveground biomass; $y = -46.18 + 3.327x$	0.841*
Grain yield; $y = -101.076 + 7.237x$	0.973**
Plant height; $y = -14.488 + 0.965x$	0.984**
Straw yield; $y = -2.362 + 0.175x$	0.971**
Yield reduction $= -406.39 + 43.255$CD	0.975**
Yield reduction $= -248.93 + 7.874$DBH	0.988**

*$P < 0.05$, **$P < 0.01$, CD, Crown diameter and DBH, Diameter at breast height.

Density (plant number m^{-2}) of paddy crop varied from 89.6 under 28-yr-old tree at 1 m distance to 103.9 under 6-yr-old tree at 7 m distance from the tree base (Figure 2 *a*). Per cent reduction of plant density was significantly related to age (Table 3). On average across the distance maximum reduction of 9.45% occurred under 28-yr-old tree and minimum under 6-yr-old tree compared to that of the open field. Except for the 6-yr-old tree, the crop density increased significantly with increasing distance from the tree trunk for all age groups (Figure 2 *a*). Effective tillers (number) per plant ranged from 2.8 to 4.4 at 1 m distance and 3.2 to 4.4 at 7 m distance (Figure 2 *b*). Per cent reduction was maximum under 28-yr-old tree (28.54%) and minimum under 6- and 9-yr-old tree (1.12%).

Within all tree age groups, plant height ranged between 79.9 and 84.1 cm across the distances from the tree base (Figure 2 *c*). The average plant height increased from 80.53 cm under 9-yr-old tree to 83.6 cm under 28-yr-old tree. Per cent increase in height was significantly correlated with tree age (Table 3).

The total aboveground biomass ranged from 0.71 to 0.861 t ha^{-1} across the tree age and at different distances from the tree. The minimum values were reported at 1 m distance (0.71–0.78 t ha^{-1}) and maximum at 7 m distance (0.83–0.86 t ha^{-1}). The average aboveground biomass across the distances from the tree base and tree age ranged from 0.79 to 0.84 t ha^{-1}, whereas in the open field it ranged from 0.81 to 0.90 t ha^{-1}. Under 6-yr-old tree, the aboveground biomass was slightly more (1.12%) compared to the open field. On average, 9% aboveground biomass was reduced across the tree age with maximum

of 11.24% under 15, 18, 22 and 28-yr-old trees and minimum of 3.45% under 12-yr-old tree compared to the open field (Figure 2 d).

Higher quantity of straw yield was reported at 1 m distance and decreased towards the periphery of the tree crown (Figure 2 e). On average across the distances it increased significantly with increase in tree age and crown diameter (Table 3).

Grain yield was lowest at 1 m distance and increased with increasing distances from the tree base under all tree age groups (Figure 2 f). It was maximum in the open area except under 6-yr-old tree, where it was reported maximum at 5 m distance. On average across the distances there was a slight increase (3.85%) in grain yield compared to the open field, as the tree canopy was not very dense under 6-yr-old tree and had less effect on grain yield. The yield was reduced by 44.4% under 28-yr-old tree and 3.2% under 6-yr-old tree at 1 m distance, whereas at 7 m distance maximum reduction (15.8%) was observed again under 28-yr-old tree and minimum (4.1%) under 12-yr-old tree compared to the open field. Under 6- and 9-yr-old trees there was no reduction in grain yield at 7 m distance from the tree base because the tree canopy could not reach up to this distance. The average reduction in grain yield across the distances increased significantly ($r = 0.973$; $P < 0.01$, Table 3) with increasing age, tree crown and DBH of the tree from 4.7% under 9-yr-old tree to 28.8% under 28-yr-old tree compared to the open area (Figure 3).

Figure 4 shows the changes after cutting of the branches under different tree age groups and at different distances from tree base. After cutting (removal) of the tree branches the tree crown diameter decreased with maximum of 3.8% in 18 yr-old tree and minimum of 0.8% in 28-yr-old tree (Table 2), because the long and wide basal branches were cut. We have observed the changes in different crop para-
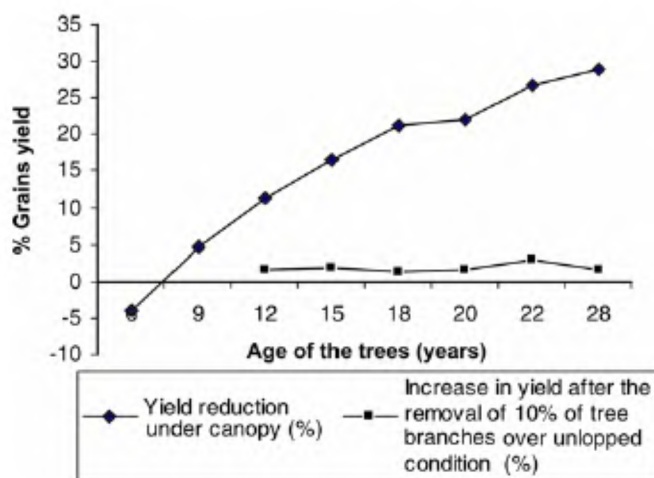
meters after cutting of the 10% of basal tree branches. The density and number of effective tillers of rice crop increased significantly with tree age over the unlopped conditions from 0.05% (under 12-yr-old tree) to 1% (under 28-yr-old tree) and from 1.19% (under 12-yr-old tree) to 5.80% (under 28-yr-old tree) across the distances respectively (Table 4). Whereas the height of the crop plants decreased significantly ($r = 0.977$; $P < 0.01$) with tree age from 0.09% (under 12-yr-old tree) to 1.32% (under 28-yr-old tree). Decrease in straw yield was reported maximum (3.85%) under 22-yr-old tree and minimum (1.92%) under 28-yr-old tree.

The maximum effect of 10% canopy removal (average across tree age) was observed at 1 m distance (2.47% increase in yield) and minimum at 7 m distance (1.06% increase in yield) under all tree age groups. Per cent increase in yield over that under unlopped trees ranged from 0.3 at 3 m distance under 18-yr-old tree to 5.15 at 5 m distance under 22-yr-old tree (Figure 4). Per cent increase across the tree age and distance over unlopped tree was minimum under 18-yr-old tree (1.4) and maximum under 22-yr-old tree (2.92) and correlated with age (Table 4).

In the present study plant density, number of effective tillers, aboveground biomass and grain yield decreased with increase in age of A. nilotica trees and showed significant correlation for majority of crop parameters with tree age. The height of crop plants and straw yield increased with the age of trees, whereas it decreased along with the distance from the tree base towards the periphery. As the age of the tree increased its crown diameter and DBH also increased significantly; thus light becomes the limiting factor. The increased height of crop plants under the tree shade showed the tendency of the plants to approach sunlight for photosynthesis. Thus the plants attain more height under the canopy compared to the open area. This has also affected the straw yield, which increased with the age of the tree. It was reported that about 62% of sunlight was reduced under the large tree canopy (>15-yr-old tree) and 44% under small tree canopy (<15-yr-old tree). There was about 30% grain yield reduction under large tree canopy and lowest up to 12% under small tree canopy, mainly due to reduction in the amount of light (44–62%)[4]. In the present study, there was a slight increase (about 4%) in grain yield under 6-yr-old tree, where the canopy was sparse and sunlight

Figure 3. Average yield reduction of rice under different A. nilotica tree age groups and changes in yield after removal of 10% of tree branches.

Table 4. Regression equation and correlation coefficient for per cent increase in different parameters (y) of rice crop vs tree age (x) after 10% canopy reduction

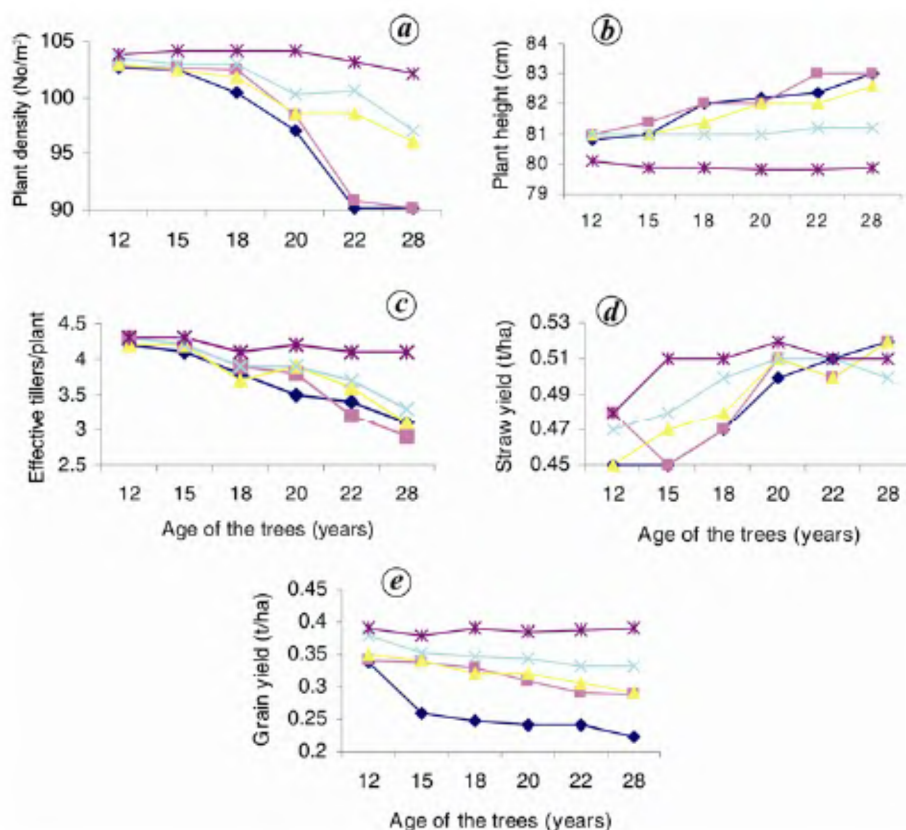| Regression equation	Correlation coefficient (r)
Plant density; $y = -5.494 + 0.304x$	0.943*
Effective tillers; $y = -46.66 + 2.598x$	0.973*
Grain yield; $y = -24.523 + 1.375x$	0.298[NS]

*$P < 0.01$; NS, Not significant.

Figure 4. Mean values of different crop parameters across rice fields after cutting 10% of tree branches: *a*, Density; *b*, Plant height; *c*, Effective tillers; *d*, Straw yield and *e*, Grain yield measured at different distances from *A. nilotica* trees. ——◆——, 1 m distance; ——■——, 3 m distance; ——▲——, 5 m distance; ——✕——, 7 m distance and ——✱——, open field.

Table 5. Calculated *F* values from ANOVA for different characters

	Without 10% branch cutting			With 10% branch cutting		
Character	Age	Distance	Age × distance interaction	Age	Distance	Age × distance interaction
Grain yield	3.55*	9.39*	0.44^{NS}	44.03*	300.05*	6.61*
Plant density	87.49*	50.69*	8.14*	117.51*	85.69*	12.38*
Straw yield	3.63*	0.37^{NS}	0.10^{NS}	4.25*	1.12^{NS}	0.38^{NS}
Effective tillers	9.53*	3.32**	0.66^{NS}	13.26*	4.93*	0.66^{NS}
Plant height	13.84*	25.38*	1.42^{NS}	2.24^{NS}	11.15*	0.45^{NS}

*$P < 0.01$; **$P < 0.05$; NS = Not significant.

could easily penetrate the canopy and reach to the soil/crop. Increase in organic matter and soil nutrients has already been reported under these leguminous trees[10,12]. The combined effect of light, organic matter and soil nutrients might have increased the grain yield under this young tree. Blackman[13] has also supported the concept of multiple limiting factors that plant productivity respond to increased inputs of only the most limiting factors until another becomes limiting. With trees more than 9-yr-old, the grain yield decreased from 4.7% (under 9-yr-old tree) to 28.8% (under 28-yr-old tree). From ANOVA (Table 5), it is clear that tree age and distance from the tree base

significantly affect all the crop parameters with or without branch cutting, whereas the interactions of age and distance significantly affect the grain yield and plant density.

Increased plant height, more straw yield and decreased effective tillers under the tree canopy showed that it favours vegetative growth and biomass and adversely affects reproduction. On the one hand, from an ecological point of view, the ecosystem is not losing the total biomass production (straw yield + grain yield) because the total aboveground biomass is reduced up to 11% for 28-yr-old trees. On the other hand, the tree gives direct return and

indirect benefits to the soil system, especially by increasing the nitrogen cycling and organic matter and also checking soil erosion.

Farmers allow the growth of *A. nilotica* in their rice field bunds because they get wood (an average of about 4 q/tree/yr from the tree below the age of 10 years) and utilize it as fuelwood or as fencing material for crop protection[3]. From the age of 10 years onwards wood production ranges from 4 to 5 q/tree/yr, which is used for agricultural implements, construction of doors and frames, etc. Gautam[14] reported 50–200 q total wood production per tree after the age of 20–25 years, which includes 2–4 m[3] merchantable timber. Economic analysis reveals that at the age of 20–25 years, the farmers get on an average around Rs 2000 for each tree and Rs 50,000 to Rs 1.5 lakh from one hectare depending upon its stocking rate, which not only compensates the yield loss but also provides extra income. Tarafdar and Ray[15] have found that the roots and aboveground leaves or plant residues are the major components of litter in the tree-based systems which contribute to increasing soil organic matter and improving many soil properties like bulk density, soil aggregates, pore size distribution, etc. These, in turn, provide higher water-holding capacity, favourable permeability, better aeration and rooting environment in soil[16–18]. The 10% canopy removal has significantly increased the plant density, effective tillers and grain yield. Pandey and Sharma[4] have reported that light is the main cause of reduction in crop yield in this area. In the present study when the lower branches were removed, light penetration might have increased because the crown diameter had already been reduced (0.8–3.8%), which ultimately increased crop production.

To conclude, *A. nilotica* tree reduces the rice crop yield in the sub-humid regions of the Chhattisgarh plains. The removal of 10% of basal tree branches increases the grain yield without having any adverse effect on the tree component. This study suggests that the traditional agroforestry systems should not be discouraged, as they are needed for the sustainability of the agroecosystem. So the farmers of this region should use management practices having less expenditure, in which grain yield reduction under traditional agroforestry system could be minimized and the branches can be used as fuelwood as well as fodder. This study also indicates that there are further possibilities and potentialities to sustain the long-term ecosystem services of traditional agroforestry systems which need to be developed to solve the land management possibilities of the Chhattisgarh plains, for which the farmers' cooperation is also needed.

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