

## Effect of Canopy Size of *Acacia nilotica* on Rice (*Oryza sativa* L.) Productivity in a Traditional Agroforestry in the Central India

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**Abstract:** Influence of different canopy sizes (large, medium and small) of *Acacia nilotica* on the growth and yield of rice crop was evaluated in a traditional agroforestry system in a dry tropical climate of India. Light intensity at ground level was lowest at 2 m from the tree trunk and increased with the distance. Maximum light was under the large tree canopy (62%) and minimum under the small tree canopy (44%). Soil organic C and total N were greater by 53% and 113%, respectively, under the large tree canopy, and 44% and 78%, respectively, under the small tree canopy compared to open field. Contrary to higher organic C and total N, C/N ratio in the soil was lower under all the canopy sizes. Crop density, above-ground/below-ground biomass ratio and grain yield under all the canopy sizes were lowest at 2 m from the tree trunk and increased with the distance. The crop density, yield and Ab/Bb ratio were reduced maximum 35, 30 and 15%, respectively, under the large tree canopy and minimum 17, 12 and 1.3%, respectively, under the small tree canopy. Harvest index declined under the large tree canopy compared to open field. On the contrary, it increased under the small tree canopy, but grain yield declined.

**Key words:** Canopy size, soil organic C, total N, limited light, competitive and complementary interactions

Soil-water, light and nutrients are three major growth limiting resources in agroforestry. Generally, tree and crop components develop competition for these limiting resources (Huxley *et al.*, 1989; Ong *et al.*, 1991). Trees modify the resource availability to understorey crops and as a result develop either competitive or complementary interactions, which cause either detrimental or beneficial effects on crop production. However, extent of influence depends upon the size of tree canopy.

*Acacia nilotica* (L.) Willd. ex Del is a multipurpose tree legume which grows

naturally in the Chhattisgarh state of central India and forms an important traditional agroforestry system (Pandey *et al.*, 1999, 2000). The tree is socially acceptable as it provides fuel, fodder, timber, gum and local medicines. But, paddy cultivation depends generally on the amount and distribution of rainfall. When rainfall does not occur after flowering soil-water becomes limiting similar to that in semi-arid and arid conditions and affect the crop production. Therefore, *A. nilotica*-rice crop interaction is pertinent from the crop management viewpoint.

The study was designed to obtain information on the effect of different canopy sizes of *A. nilotica* on the growth and productivity of *Oryza sativa* (rice) in a

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traditional agroforestry system in Chhattisgarh state of central India.

## Materials and Methods

### Study area

The study sites were located 292 m above sea level in Bilaspur district (21°37'-23°87'N latitude and 81°12'-83°19'E longitude) of Chhattisgarh. Soils were vertisols, brown to black in color, clay to clay-loam in texture, montmorillonitic in nature and poor to moderate in nutrients (Pandey *et al.*, 2000).

The year is divisible into three seasons: rainy (mid June-Sept), winter (Nov-Feb) and summer (mid Feb-June). Mean monthly maximum temperature varied from 25.4°C in January to 40.5°C in May and mean monthly minimum from 11.2°C in January to 27.1°C in June. Mean annual rainfall is 1221 mm of which 88% occurs during rainy season. A long dry period for 7 to 8 months, from October to May, prevails in the region, which makes the climate seasonally dry similar to that of arid and semi-arid conditions.

Rice-based cropping system is predominant in the region. Rice is sown during the rainy season, followed by winter crops such as *Linum usitatissimum* L., *Triticum aestivum* L. and *Lathyrus sativus* L. Crops are sown generally close to the trunk of tree. Soil tillage practices and crop management operations are same beneath and outside the tree canopy. *Acacia nilotica*, having an average height of 7.75 m and density 30 trees ha<sup>-1</sup> is distributed in the study sites.

### Sampling design

**Vegetation:** A total of 30 trees, of which 10 each of small canopy size (6 m diameter),

medium canopy size (6-10 m diameter) and large canopy size (10-14 m diameter) were selected randomly in the rice fields near Sendri village. Rice (var. Swarna) was transplanted in all the fields at 20 cm row-to-row distance. Within a row plant-to-plant distance was 10 cm. Only one tree, mutually exclusive (45-50 m apart) of its neighbor tree, in each rice field was selected. Thus, there were 30 rice fields each having one tree. Five radial transects from tree trunk were laid down randomly under each tree canopy. The crop was sampled along the transects at 2, 4, 6, 8, 10, 15, 20 and 25 m distance from the tree trunk. The open field, at 25 m distance, was treated as control.

A quadrat of 1 x 1 m size was laid down at each sampling distance and number of tillers were counted in 1 x 1 m quadrat and grain yields were measured. Below-ground biomass was determined by monolith (15 x 15 x 15 cm) method from each harvested plot. Plant materials were dried to constant at 80°C weight. Tillers, above-ground biomass and below-ground biomass of rice in 1 m<sup>2</sup> quadrat were recorded just before the flowering. However, grain yield was measured at the time of crop maturity. Harvest index (HI) was calculated.

Light intensity was measured from 7 AM to 2 PM at 2 h interval at respective sampling distance along the transect by a digital lux meter (Lutron LX-101).

### Soil

Soil was sampled randomly at 10 places under each tree canopy and in the open field (at 25 m distance) at 0-10 cm, 10-20 cm and 20-30 cm depths. Soils of respective

depth were mixed and composite samples were prepared and analyzed for organic C by Walkley and Black rapid titration method and total N by microkjeldahl digestion method. Soil moisture (0-15 cm) was estimated on dry weight basis by oven drying 100 g soil at 105°C for constant weight.

### *Statistical analysis*

Crop data were analyzed using split-plot (canopy size; main plot, distance; sub-plot) for analysis of variance. Soil data included 3 canopy sizes (main-plots), 2 levels of tree canopy positions (sub-plots) and 3 soil depths (sub-sub-plots). Number of rice fields served as replicates. Least significant differences (LSD) were calculated from appropriate SED to estimate the significance of differences between two means. Regression and correlation coefficient analysis were done to assess the relation between parameters.

### **Results and Discussion**

Maximum sunlight (62%) was reduced maximum under large tree canopy and minimum (44%) under small tree canopy. Intensity of light was correlated with the distance ( $r = 0.89$ ,  $P < 0.01$ ). Intensity of light varied with tree canopy size ( $P < 0.01$ ) and distance  $P < 0.01$ ). Interaction between tree canopy size and the distance was also significant ( $P < 0.05$ ).

Soil organic C was 53% greater under the large tree canopy and 44% greater under small tree canopy compared to that in open field (Table 1). Similarly, total N was greater by 113% under large tree canopy and by 78% under small tree canopy compared to that in open field. Soil organic C and

total N were affected due to the tree canopy sizes ( $P < 0.001$ ), tree canopy positions ( $P < 0.001$ ) and the soil depths ( $P < 0.001$ ). Interaction between tree canopy sizes and tree canopy positions on soil organic C and total N was also significant ( $P < 0.05$ ). C/N ratio was lower by 37% under large tree canopy and by 9% under small tree canopy compared to that in open field (Table 1). C/N ratio varied with the tree canopy sizes ( $P < 0.01$ ). Interaction between tree canopy size and tree canopy position ( $P < 0.001$ ) was also significant.

The rice crop density was reduced maximum 35% under the large tree canopy and minimum 17% under small tree canopy. Similarly the Ab/Bb ratio was reduced 15% under the large tree canopy and minimum 1.3% under the small tree canopy. Density and above-ground/below-ground biomass (Ab/Bb) ratio were affected due to tree canopy size ( $P < 0.01$ ) and distance ( $P < 0.01$ ). Interaction between the tree canopy size and the distance was also significant ( $P < 0.05$ ).

Decline in density and Ab/Bb ratio of the rice crop under the tree canopy compared to that in open field seem to be mainly due to limited light. Shade reduces photosynthetic rate and allocate greater photosynthate to below ground parts (Wild *et al.*, 1993). Intensity of light in the present study was reduced, whereas concentrations of soil organic C and total N were higher and C/N ratio was lower indicating greater availability of nitrogen under the tree. Our results are similar to these finding observed by Farrell (1990) who found that soil nutrient pool (Total C, N and exchangeable cations) and water were higher beneath the crowns of trees compared to that in open fields

Table 1. Soil organic C, total N and C/N ratio under different tree canopy sizes of *Acacia nilotica*.

Parameters	Soil depth	Large tree canopy (10-14 m)		Medium tree canopy (6-10 m)		Small tree canopy (< 6 m)	
		Beneath canopy	Open field	Beneath canopy	Open field	Beneath canopy	Open field
Organic C (%)	0-10	a1.21a	b0.78b	a1.05a	b0.60b	a0.71a	b0.50b
	10-20	b1.06b	a0.67a	b0.82b	a0.50a	a0.69a	c0.44c
	20-30	c0.77c	a0.52d	c0.69c	a0.46a	a0.54d	c0.41c
	Mean	1.01x	0.66y	0.85x	0.52y	0.65x	0.45y
Total N (%)	0-10	a0.112a	a0.054d	a0.104a	b0.049b	a0.077a	b0.043b
	10-20	b0.094b	d0.048d	b0.078b	a0.037a	b0.051b	a0.027a
	20-30	c0.044c	e0.015e	c0.026c	d0.015d	c0.016c	c0.012c
	Mean	0.083x	0.039y	0.069x	0.034y	0.048x	0.027y
C/N ratio	0-10	a10.80a	b14.44b	a10.10a	b12.25b	a 9.22a	b11.63b
	10-20	a11.28a	b13.96b	a10.51a	b13.51b	b13.53b	a16.30a
	20-30	d17.50d	c34.67c	d26.54d	c30.67c	c33.75c	c34.17c
	Mean	13.19x	21.02y	15.72x	18.81y	18.83x	20.70y

Values of a parameter in a row suffixed with different superscripts are significantly different at  $P < 0.05$ .

Values of a parameter in a column prefixed with different superscripts are significantly different at  $P < 0.05$ .

in a Mexican farm land, but the yield of maize declined due to limited light. However, lowest reduction in density and Ab/Bb ratio under small tree canopy indicated that rice crop responded lowest to the low level of shade (44% reduction in light) under the soil moderately rich in nutrients (480 mg kg<sup>-1</sup> total N, and C/N ratio = 19). The crop could not utilize high concentration of total N (830 mg kg<sup>-1</sup>) and greater availability of mineral N (C/N = 13) under high level of shade under large tree canopy (62% reduction in light). This suggests that tree canopy can be managed for its lowest effect on the crop growth and grain yield either through the management of its size or stocking rate of the tree itself.

#### Rice yield

Grain yield was reduced highest (30%) under the large tree canopy and lowest

(12%) under the small tree canopy (Fig. 1). Among the non-linear equations, logarithmic model explained maximum variability in grain yield with the distance ( $r^2 = 0.89-0.91$ ,  $P < 0.01$ ) under all the tree canopy sizes. Grain yield of the crop was minimum at 2 m from tree trunk and increased with the distance ( $P < 0.01$ ) under all the tree canopy sizes ( $P < 0.01$ ). Like grain yield, HI was highest at 2 m from the tree trunk under small tree canopy and declined ( $P < 0.05$ ) with the distance. HI was 3% higher under the small tree canopy compared to that under large tree canopy.

Reduction in grain yield under the large canopy was consistent with reduction in HI. However, increase in HI under the small canopy compared to that in open field indicated that light and soil-water were comparatively greater under the tree canopy.

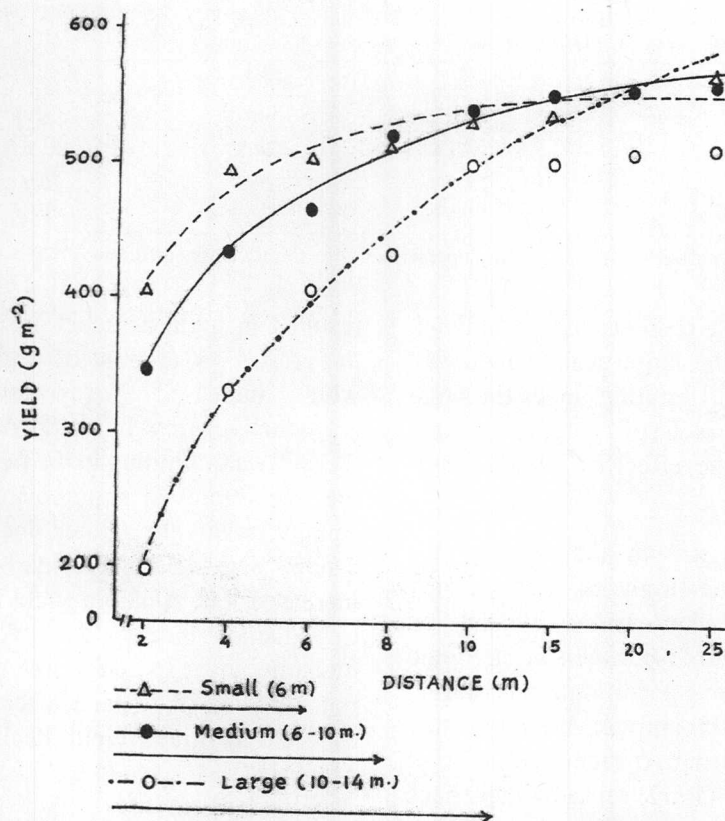


Fig. 1. Relationships between distance and yield under large tree canopy:  $Y = 142.7911 + 130.3256 (\ln d)$ , ( $r^2 = 0.891$ ,  $P < 0.01$ ); under medium tree canopy:  $Y = 314.0284 + 85.7551 (\ln d)$ , ( $r^2 = 0.910$ ,  $P < 0.01$ ) and under small tree canopy:  $Y = 390.7125 + 56.6314 (\ln d)$ , ( $r^2 = 0.911$ ,  $P < 0.01$ ).

Soil-water in the rice field during reproductive growth phase of the crop seem to have become limiting as the rainfall amount lowered to 76 mm, whereas pan-evaporation increased by 7% compared to that during vegetative growth phase. Van Noordwijk (1996) reported that whenever, rainfall is less than 150 mm per month in the growing season and evapotranspiration  $4 \text{ mm day}^{-1}$ , water becomes limiting to crops. However, soil moisture in the present study during the reproductive

growth period of the crop (November-December) was found 39% higher under the large tree canopy and 20% higher under the small tree canopy compared to open field (Table 2). Comparatively higher soil-water increased the partitioning of dry matter to grains in low level of shade under the small tree canopy. But apparent grain yield declined due to reduction in crop density. Rhoades (1995) recorded 4 to 53% increase in soil-water under the canopy of *Faidherbia albida* compared to that in

Table 2. Soil moisture under different canopy size of *Acacia nilotica* and corresponding open field during reproductive growth period of rice

Month	Tree canopy size			
	Large	Medium	Small	Open field
October	27.5	25.1 <sup>a</sup>	24.8	21.8
November	24.9	22.4	20.2	15.8
Mean	<sup>a</sup> 26.2	<sup>ab</sup> 23.8	<sup>b</sup> 22.5	<sup>c</sup> 18.8

Values in a row prefixed with different superscripts are significantly different at  $P < 0.05$ .

open sites during crop season in Malawi. Low HI under the large canopy indicated that light was still limiting under the large canopy and increased soil-water could have not moderated the effect of high level of shade.

Reduction in growth and yield of rice crop beyond the limit of tree canopy indicated that below-ground competition might have occurred between the tree and crop to some extent for nutrients during vegetative growth and for both moisture and nutrients during reproductive phase of the crop. Coster (1932) reported that shade effects of *Tectona grandis* extended over a few meters from old stand while apparent root competition occurred over approximately 20 m.

Our study concludes that *Acacia nilotica* enriched soil under its canopy with organic C and total N, but latter comparatively greater which made the C/N ratio lower. Tree canopy reduced light and made it limiting to the understorey crop. However, reduction depended upon the tree canopy size. The rice crop responded to available nitrogen maximally under low level of shade under the small tree canopy. As a result lowest reduction in crop density occurred under the small tree canopy. The crop could not utilize high availability of nitrogen under dense shade of large tree canopy which

resulted in highest reduction in density of the crop. Low amount of rainfall together with increased evaporation during reproductive growth period perhaps made the soil-water limiting in the field. However, the tree improved soil moisture under its canopy, relatively greater under the larger canopy size. HI under small canopy size increased, but apparent yield declined due to reduction in crop density. Higher soil moisture under the large tree canopy could not moderate the shade effect. Hence, HI as well as grain yield declined.

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