Journal of Tropical Biodiversity and Biotechnology
Volume 08, Issue 03 (2023): jtbb78063
DOI: 10.22146/jtbb.78063

Research Article

Comparison of Light Intensity under the Canopy between Sal (*Shorea robusta*) and Akashmoni (*Acacia auriculiformis*) in Agroforestry Stands: Effect of Tree Size and Distance from Individual Trees

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Keywords:
agroforestry
canopy
Interception
light environment
RPAR
Submitted:
28 September 2022
Accepted:
10 April 2023
Published:
08 September 2023
Editor:
Furzani Binti Pa'ee

ABSTRACT
Agroforestry is now inevitable for meeting the snowballing demand for food of the growing number of people worldwide. The light environment is the most important driving force for the growth and development of crops in agroforestry stand. The present study aims to quantify the light interception in two different agroforestry types, where one was composed of *Shorea robusta* (Sal) with *Ananas comosus* and another was *Acacia auriculiformis* (Akashmoni) with *Ananas comosus.* The relative Photosynthetically Active Radiation (PAR) was measured by a pair of quantum sensors in four directions from some individual trees. Spatial variation of PAR was also explored in both stand types. The results revealed that RPAR did not significantly (P>0.05) vary among four directions of individual trees in *S. robusta* but the *A. auriculiformis* showed a significant difference (P<0.001) along the four directions. Also, RPAR was significantly different (P<0.001) at different distances from individual trees under the canopy of both tree species. When the stand-level spatial variation of RPAR was considered, *A. auriculiformis* (0.177) and *S. robusta* (0.171) showed no significant difference (P>0.05) in the light environment. Our findings explored that both the tree species would be suitable species for agroforestry practices in the area. For the betterment of the natural *S. robusta* forest responsible authorities should encourage people to avoid *A. auriculiformis* plantations near the natural *S. robusta* forest which will enhance the conservation of *S. robusta* cover in its natural habitat.

INTRODUCTION
The present world is facing significant challenges of food, fuel wood, fodder and other agriculture and forest products due to global population growth. It is very problematic to fulfill food and forest product demand with detaching practice of agriculture and forestry because of land scarcity (Licker et al. 2010). There are approximately 80-120% rise in global food demand by 2050 because of global population growth and alteration of dietary intake (Tilman et al. 2001; FAO 2006; Foley et al. 2012). In this challenging global situation, agroforestry practice is one of the best options to meet those challenges (Dufour et al. 2013) worldwide as well as in Bangladesh. Agroforestry has numerous benefits including biodiver-

sity conservation (George et al. 2013), food production, carbon sequestration (Nair et al. 2009), effective resource use (Munz et al. 2014) and soil improvement (Udawatta et al. 2008). Agroforestry also plays an important role to promote green economy, sustain agriculture landscape (Schroth & Mota 2013), stimulate long-term sustainable and renewable forest management (Gold 2017), and reduce soil erosion and desertification (Branca et al. 2013). Generally, people prefer fast-growing cover crops that can reduce nutrient losses and soil erosion in the establishment of agroforestry stands (Fageria et al. 2011). But the best combination of trees and crops are still unknown in agroforestry system of Bangladesh.

Madhupur Sal (*Shorea robusta*) forest is the largest belt of *Shorea robusta* forest in Bangladesh situated in Tangail and Gazipur district (Rahman et al. 2009). Land tenure and encroachment become a serious problem in this forest management and conservation. The local people started to convert the forest area into agricultural land through clear-felling, without any permission from the government or forest department (FD) (Safa 2004). In this situation, Bangladesh forest department (BFD) decided to give access to the local people for agroforestry practice in existing forest areas to protect the Madhupur Sal forests from further degradation.

In agroforestry practice, light environment is a significant driver for the growth and development of crops (Forester 2014). It also found that the harvest product of tree-crop intercropping was better than in monoculture crops, exclusively a new pattern for light utilization (Whiting 2011). Trees and crops compete for various growth resources mainly light that drives the energy available for photosynthesis and transpiration (Alam et al. 2018; Liu et al. 2021). However, the photosynthetically active radiation (PAR), light interception and light use efficiency increase the yield of intercropping (Marshall and Willey 1983; Gao et al. 2010; Ceotto et al. 2013; Du et al. 2015; Wang et al. 2015). In most cases, the tree canopies are responsible for light environment regulation because they work as a light barrier to crops. Light interception also controls energy balance and microclimate, which are crucial parameters of agroforestry practice for the growth and development of crops (Alam et al. 2018). In agroforestry plots, the growth of crops is influenced by the amount of photosynthetic photon flux density (PPFD) reaching the agricultural produce because their lights are intercepted by plantation crops (Willson 1999). It assumed that the light environment may vary because of species variation, density, crown volume, leaf area index, spacing, distance from tree, and height from ground. However, the knowledge of light environment in agroforestry system remains unclear.

Considering the significance of light intensity in output of agroforestry schemes, the present study aims to sketch of the light environment and its impact on two different agroforestry tree-crop combinations broadly practiced in the study area. These two tree-crop combinations are *Shorea robusta* with *Ananas comosus* and *Acacia auriculiformis* with *Ananas comosus. Shorea robusta* is a deciduous large tree. The diameter at breast height (DBH) varied from1.5-2 m with an average height ranging from 18-32 m. The bole is clean, straight and cylindrical with often bearing epicormic branches and a spherical crown (Sharma et al. 2019). The leaves are 10–25 cm long and 5–15 cm broad. In wetter areas, *S. robusta* is evergreen; in drier areas, it is dry-season deciduous, shedding most of the leaves from February to April, leafing out again in April and May. On the other hand, *Acacia auriculiformis* is an evergreen tree that grows between to 15–30 m tall, with a trunk up to 12 m long and 50 cm in diameter. The trunk is crooked and the bark is vertically fissured. It has dense foliage with an open, spreading crown. Mature leaves are linear to very narrowly elliptic and falcate with a dark green color. The leaves are glabrous, 8–22.5 cm long (average 10–20 cm) and 10–52 mm wide (average 12– 30 mm) (Orchard & Wilson 2001). The objectives of this study were to explore the variation of RPAR in the tree level and stand level, as well as explore the effect of crown volume, distance from tree and above ground biomass of individual trees on the RPAR on two types of agroforestry stands. We hypothesized that there is no significant difference in relative Photosynthetically Active Radiation (RPAR) under the canopy between the two tree species. We also hypothesized that RPAR would not vary among four directions and distance from individual trees.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in the Madhupur Sal forests (locally known as Madhupur Garh), Bangladesh's largest belt of Sal forests (Figure 1). *Shorea robusta* is the dominant species and usually forms 75% of the total tree individuals in the natural forest patches (Rahman et al. 2019). The area is located between 24°30′–24°50′ N and 90°00′–90°10′ E (Rahman et al. 2017). The area is slightly elevated and the maximum height of about 18 - 20 m from the mean sea level. The soil is yellowish red sandy clay and becomes compacted and harder when dries but melts with the rainfall and becomes soft and tenacious (Mondol 2021). All physio-chemical characteristics (soil colour, soil texture, pH, organic matter, nitrogen, phosphorus, potassium, and sulphur) of uncovered and encroached areas soil are low here in comparison to the forests covered areas (Mondol 2021). The mean annual temperature is 26°C and the average of monthly maximum and minimum temperatures are 27.5°C and 18.5°C respectively (Rahman et al. 2019).

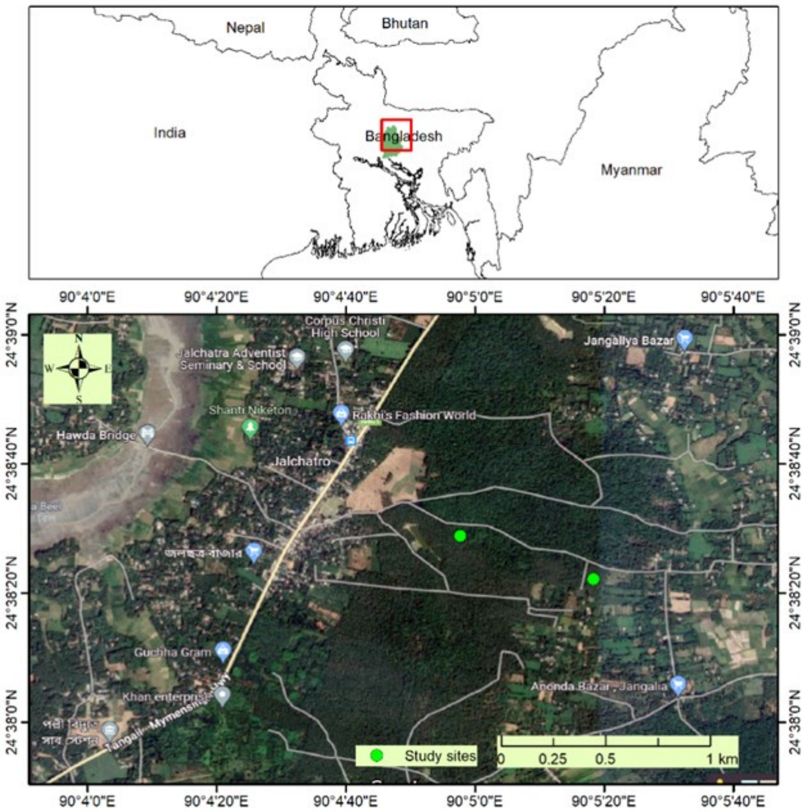

Figure 1. Map of the study sites (adapted from Google maps, maps.google.com).

Sampling Design and Data Collection

The sampling was conducted in two sample plots with total area 800 m^2. Each plot was divided into twenty subplots with 1m^2 size (Figure 2). Both sampling plots were located in agroforestry area; one was constituted with Shorea robusta and Ananas comosus and the other one was constituted with Acacia auriculiformis and Ananas comosus. Those plots were located in Dokhola range in Madhupur Sal forest, Tangail. All trees height, DBH, crown height and crown width were measured and recorded from those two plots. We consider an individual is a tree where the DBH of the trees is more than or equal to 5 cm (DBH ≥ 5 cm). Wood density of Shorea robusta and Acacia auriculiformis were collected from secondary data sources available at Global Wood Density Database (Chave et al. 2009; Zanne et al. 2009).

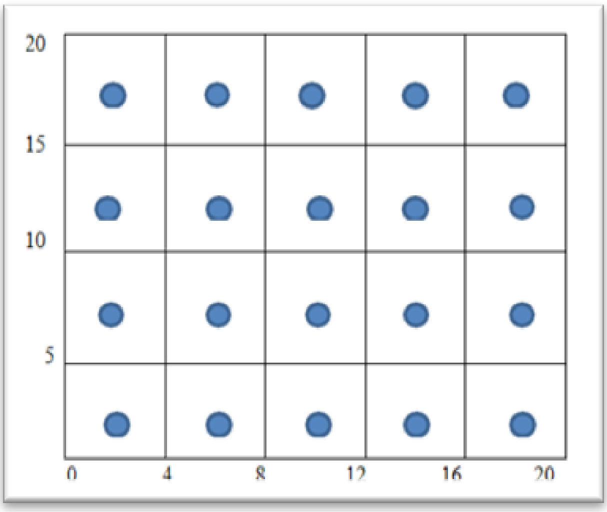

Figure 2. Photosynthetically Active Radiation (PAR) measurement points in a 20 m x 20 m plot layout.

Measurement of Photosynthetically Active Radiation (PAR) at Plot Level and Tree Level

The Photosynthetically Active Radiation (PAR) measurements were performed from 11:00 a.m. to 1:00 p.m. on sunny days during the last week of October 2017. Each plot was divided into 20 subplots. And the PAR is measured by a pair of horizontally placed quantum sensors (LI- 190SA; LI-COR, USA) and in each subplot, 25 observations of photosynthetically active radiation (PAR) were taken using a data logger (LI-1400; LI-COR, USA) (Figure 3). At tree level, the individual trees were selected randomly from those two plots. First 10 trees of Shorea robusta were selected randomly from the first plot and 10 trees of Acacia auriculiformis were selected randomly from the second plot. PAR measurement of the individual tree was performed at varied distance from the tree in four perpendicular directions (north, south, east and west) with one meter interval in each direction from tree to 5 meter distance. In each direction data was obtained at 5 points and repeated in the four perpendicular directions (Figure 3). Data were recorded in a data logger (LI-1400; LI-COR, USA).

Relative Photosynthetically Active Radiation (RPAR) Measurements

Relative Photosynthetically Active Radiation (RPAR) for each direction of every tree was measured by using Beer-Lambert law (Khan et al. 2004).

$$RPAR = UC/OC$$

Where RPAR= Relative Photosynthetically Active Radiation (the value varies from 0 to 1);
UC= Photosynthetically Active Radiation at under canopy or selected point; OC= Photosynthetically Active Radiation at open canopy or full sunlight.

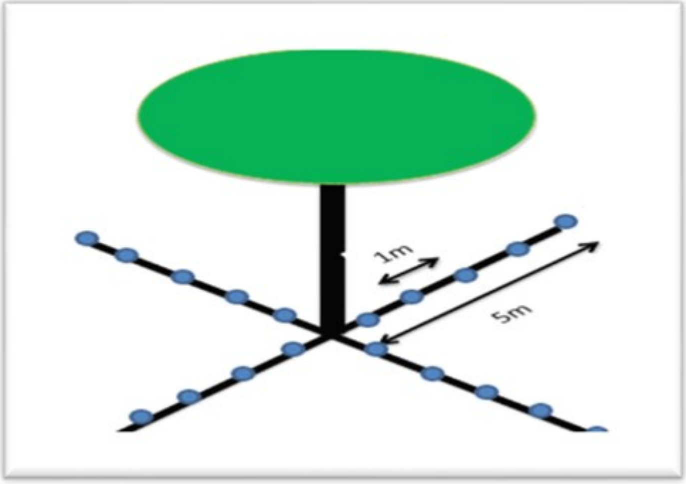

Figure 3. Photosynthetically Active Radiation (PAR) measurement points in four directions at tree level.

Crown Area Measurement

The crown diameter (CD) was calculated by using measuring tape. First, the extension of canopy was calculated in two directions from tree base to get the crown diameter. The crown base and crown top were measured by using Suunto Clinometer. The difference of crown base and top was the crown diameter. Crown Area (CA) was estimated by the following equation,

$$CA = \frac{\pi}{4}(CD)^2$$

Where, CA = Crown Area; CD = Crown Diameter.
To get the crown volume (CV), crown area was multiplied by crown height.

Aboveground Biomass Measurement

Chave et al. (2005) established a set of allometric equations for measuring the biomass of tropical trees. The equations were frequently used for measuring the above ground biomass (Pitol et al. 2019; Pitol & Mian 2023; Azad et al. 2021) worldwide. We also used the equation recommended by Chave et al. (2005).

$$AGB\ (Kg) = 0.0673 \times (\rho D^2 H)^{0.972}$$

Where, AGB = Aboveground Biomass (Kg); ρ = Wood density (g cm^{-3}); D = Diameter at breast height (cm); H = Height (m).

Statistical Analysis

A two-way-ANOVA test was performed with relative Photosynthetically Active Radiation (RPAR) as response variable against distance and direction as explanatory factors. Pearson's correlation was performed among different tree related variables, such as DBH, height, aboveground biomass, crown size, and distance from individual trees. An independent sample t-test was performed to find any significant difference of spatially distributed RPAR under the canopy of the two tree species. The statistical analysis of data was performed using the R programming language (R Core Team 2021).

RESULT

Tree Level Variation of Light Intensity in Two Species

RPAR shows strong correlations ($P<0.01$) to different tree level variables, such as DBH, height, aboveground biomass, crown size, and distance from individual trees. It was found that DBH, height, aboveground biomass, crown size, and distance from individual trees significantly affect the light environment (RPAR) in both the species *Acacia auriculiformis* and *Shorea robusta.* While the effect of crown volume of *A. auriculiformis* on RPAR was not significant ($P>0.05$) (Figure 4).

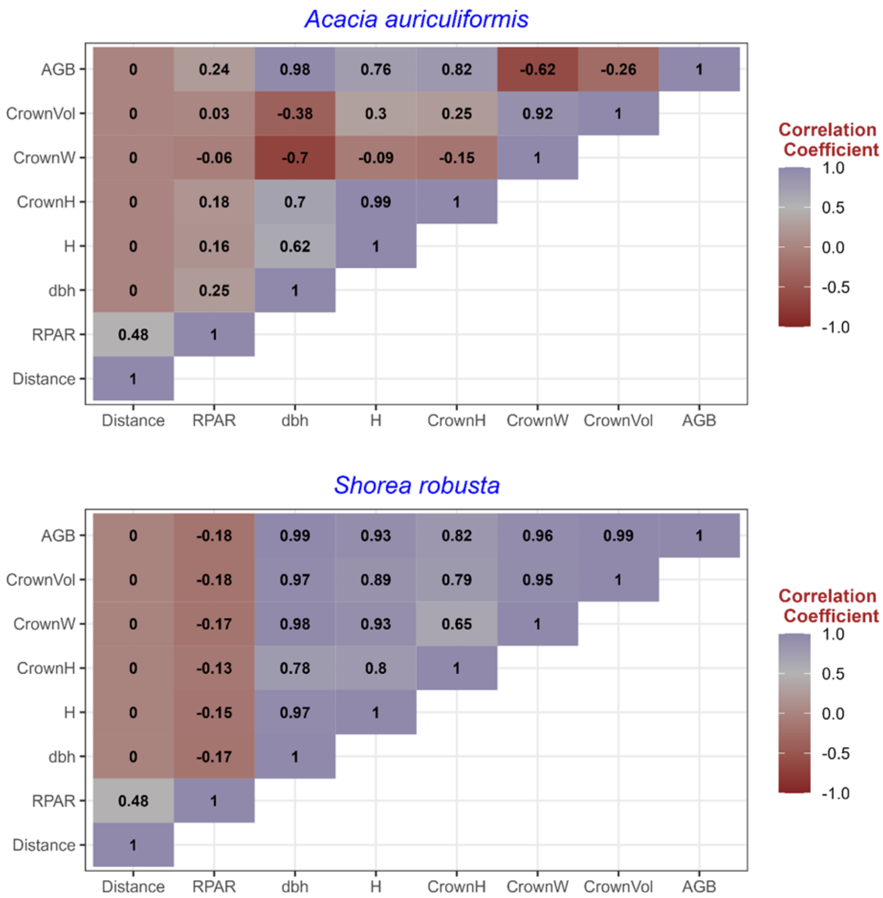

Figure 4. Pearson's correlation matrix among different tree level variables in *Shorea robusta* and *Acacia auriculiformis.* Distance = Distance from individual tree in meter, RPAR = Relative Photosynthetically Active Radiation, DBH = diameter at breast height (cm), H = height (m), crownH = crown height (m), crownW = crown wide (m), crownVol = crown volume (m^3), AGB = Aboveground biomass (kg)

RPAR do not significantly ($P>0.05$) vary among four perpendicular directions of individual trees in *Shorea robusta* while *Acacia auriculiformis* showed a significant difference ($P<0.001$) among four perpendicular directions (Table 1). Also, there was significant ($P<0.001$) effect of distance from individual trees on the RPAR intensity under the canopy of both tree species. However, the combined effect of distance and direction on RPAR was not significant for *Shorea robusta* ($P<0.241$). There was a significant ($P<0.001$) effect found between the RPAR and combined effect of distance and direction for *Acacia auriculiformis* (Table 1).

Spatial Variation of Light Intensity

The result of the analysis showed no significant difference ($P>0.05$) in the light environment of *Shorea robusta* with *Ananas comosus* and *Acacia auriculiformis* with *Ananas comosus* stand (Figure 5), having the average

Table 1. Two-way ANOVA of RPAR against distance and direction of individual trees in two species

Factor	F	P
Shorea robusta		
Distance	589.45	<0.001***
Direction	2.1072	0.097^{ns}
Interaction (Distance: direction)	1.3985	0.241^{ns}
Acacia auriculiformis		
Distance	618.182	<0.001***
Direction	4.193	<0.01**
Interaction (Distance: direction)	18.416	<0.001***

** significant at 0.01 level; ***significant at 0.001 level; ^{ns} not significant

RPAR of 0.171 in *S. robusta* and 0.177 in *A. auriculiformis*. The tree density of *Shorea robusta* was 625 stem ha^{-1} with aboveground biomass of 168.75 ton ha^{-1} whereas the density of *Acacia auriculiformis* was 900 stem ha^{-1} with aboveground biomass of 36.646 ton ha^{-1}. Although, the scenario of tree density and aboveground biomass of both tree species were different the average RPAR in both stands were similar and the height of *Ananas comosus* in two plots was also very close, ranging from 1.06 to 1.13 m.

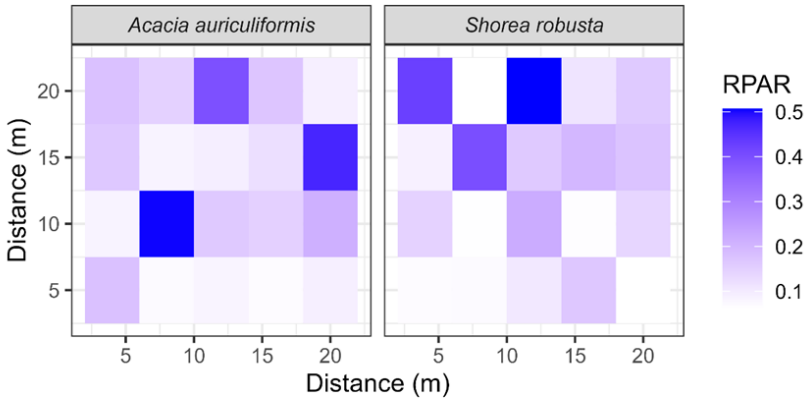

Figure 5. Stand level mean RPAR distribution in *Shorea robusta* and *Acacia auriculiformis.*

The Average RPAR Distribution with Direction

The light environment of individual tree of *Shorea robusta* and *Acacia auriculiformis* in four directions was relatively similar in trend (Figure 6). However, the results suggested that RPAR in the south direction of *A. auriculiformis* shows a distinct pattern and all other cases were similar.

The overall penetration of light at tree level is higher in *A. auriculiformis* than *S. robusta* (Figure 7) at 5 m distance from individual trees but quite similar when coming close to the trees. It was observed that the RPAR exponentially increase with increasing distance from the tree for both *S. robusta* and *A. auriculiformis* (Figure 7).

Relationship of RPAR to Aboveground Biomass with Different Distance

The aboveground biomass with different heights from the ground had significant effect on RPAR of both trees. The Figure 8 displayed the relationship between aboveground biomass and the RPAR with different distance. At 5 m distance for all tree and measured biomass the RPAR was high (> 0.5). At 4 m distance from *A. auriculiformis* the RPAR increased gradually with an increase for the aboveground biomass but fluctuate for *S. robusta*. Most of the cases the RPAR was slightly higher (> 0.3) for *A.*

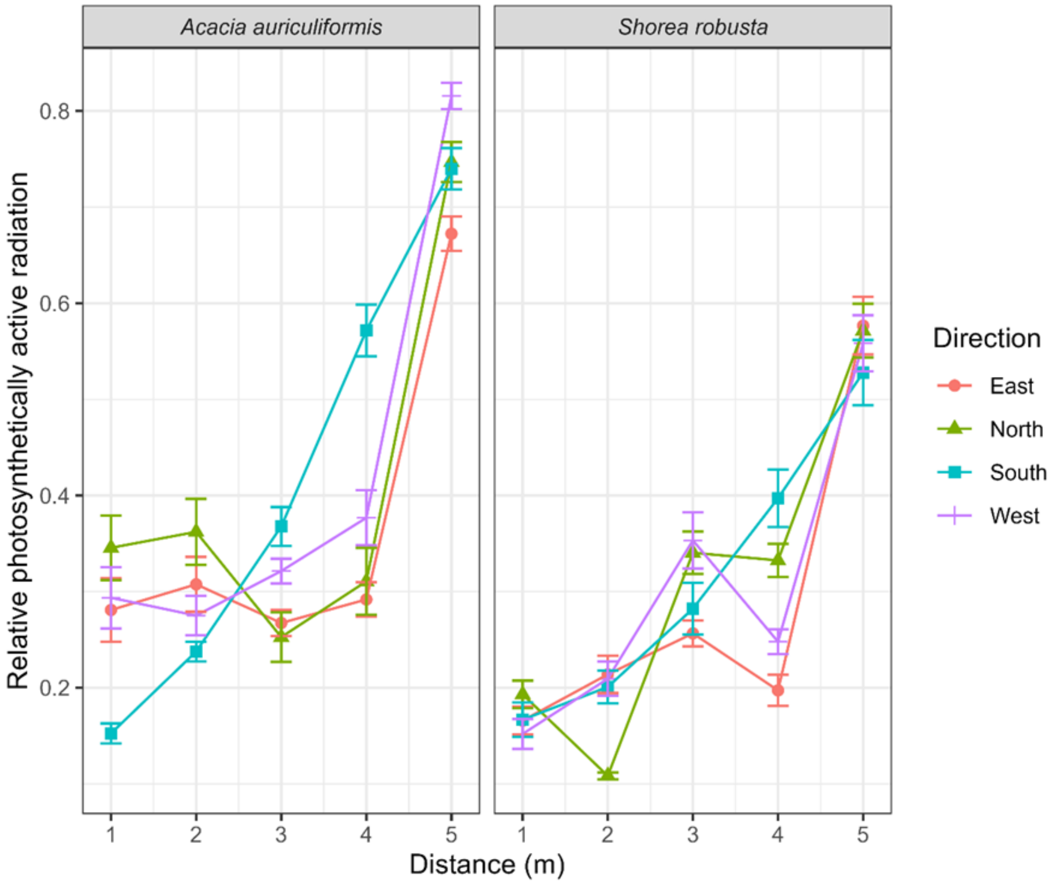

Figure 6. Relationship of RPAR to distance from the trees in four directions in *Shorea robusta* and *Acacia auriculiformis* where X-axis denotes the distance from tree, Y-axis denotes the RPAR and four colors denotes the four directions

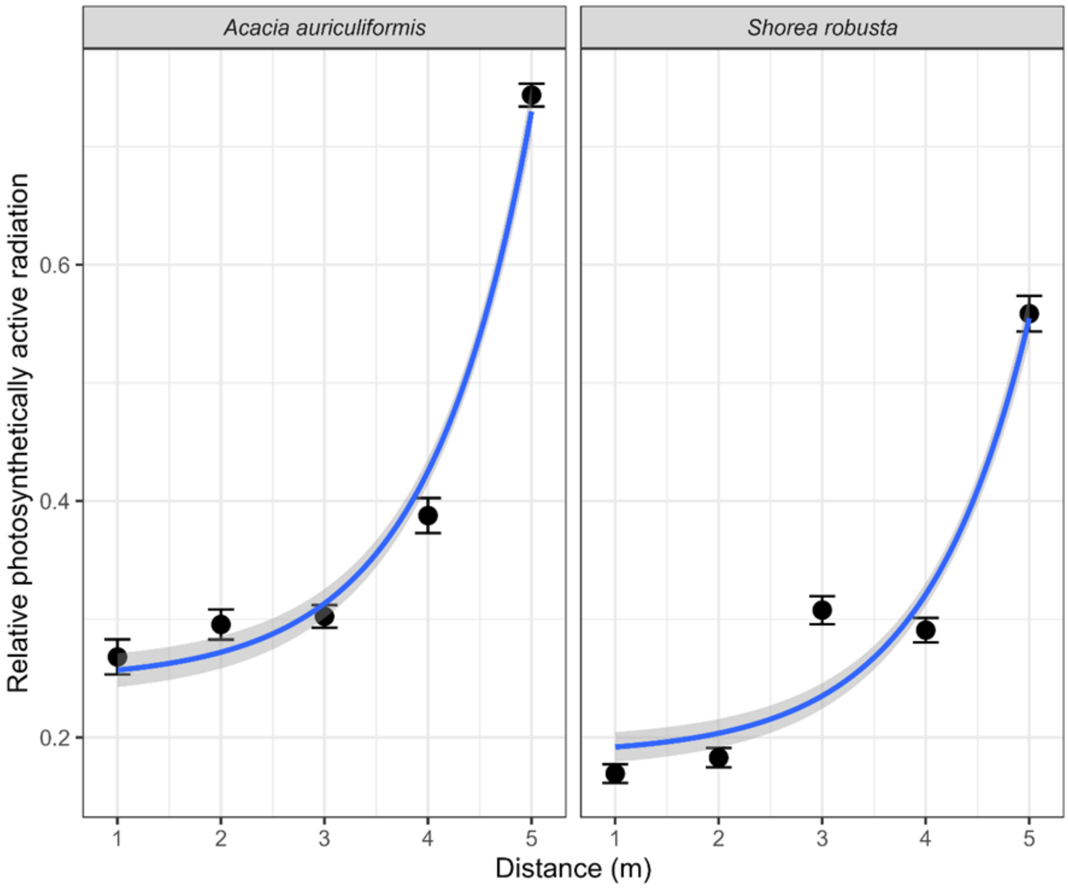

Figure 7. Relationship of RPAR to distance, where X-axis denotes the distance from tree, Y-axis denotes the RPAR

auriculiformis than the *S. robusta* (< 0.29) of having lower aboveground biomass (Figure 8).

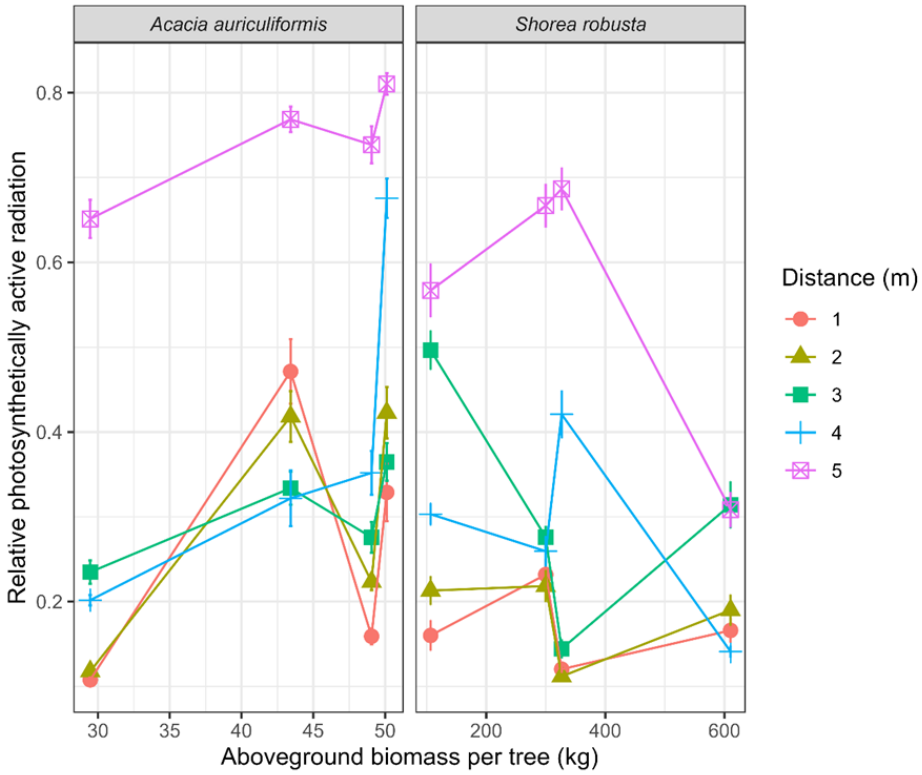

Figure 8. Relationship of RPAR to aboveground biomass per tree at variable distance in *Shorea robusta* and *Acacia auriculiformis*, X-axis denotes the biomass from tree, Y-axis denotes the RPAR, and five colors denote the distance (m) from tree

Relationship of RPAR to Crown Volume with Different Distance

The crown volume and height from ground had significant effect on RPAR of both trees. The RPAR (>0.2) sharply decrease with increase the crown volume at 3 m and 2 m distance from tree for both *Shorea robusta* and *Acacia auriculiformis* species (Figure 9). But RPAR showed increasing manner with crown volume at 5m distance from tree for *S. robusta* (>0.5) but decreasing for *A. auriculiformis* (>0.6) and the value was above 0.5 for both species (Figure 9). Also found that for 1 m and 4 m distance from tree the RPAR fluctuate with increase the crown volume for both species. The average RPAR was below 0.2 for both tree with 1m distance and above 0.3 for both tree with 4 m distance from the tree. Most of the cases *A. auriculiformis* showed the higher value (>0.35) of average relative photosynthetically active radiation (RPAR) than the *S. robusta* (<0.28) because of having lower crown volume.

DISCUSSION

Light distribution in an agroforestry plot plays vital role in the growth of crops. Tree density, size and shape effects the light interception. The leaves and canopy size of tree mainly regulates the light interception (Trápani et al. 1992; Cohen et al. 1997; Schleppi et al. 2007; Suwa 2011; Klančnik & Gaberščik 2015) and tree shading of an agroforestry system depends on the amount of leaf area per tree and crown size (Wang & Jarvis 1990; Duursma & Mäkelä 2007; Sinoquet et al. 2007). In an agroforestry system, the amount of incoming photosynthetically active radiation (PAR) to agroforestry crops is reduced by tree shading, which affects the growth and development of the production (Li et al. 2008). But we found

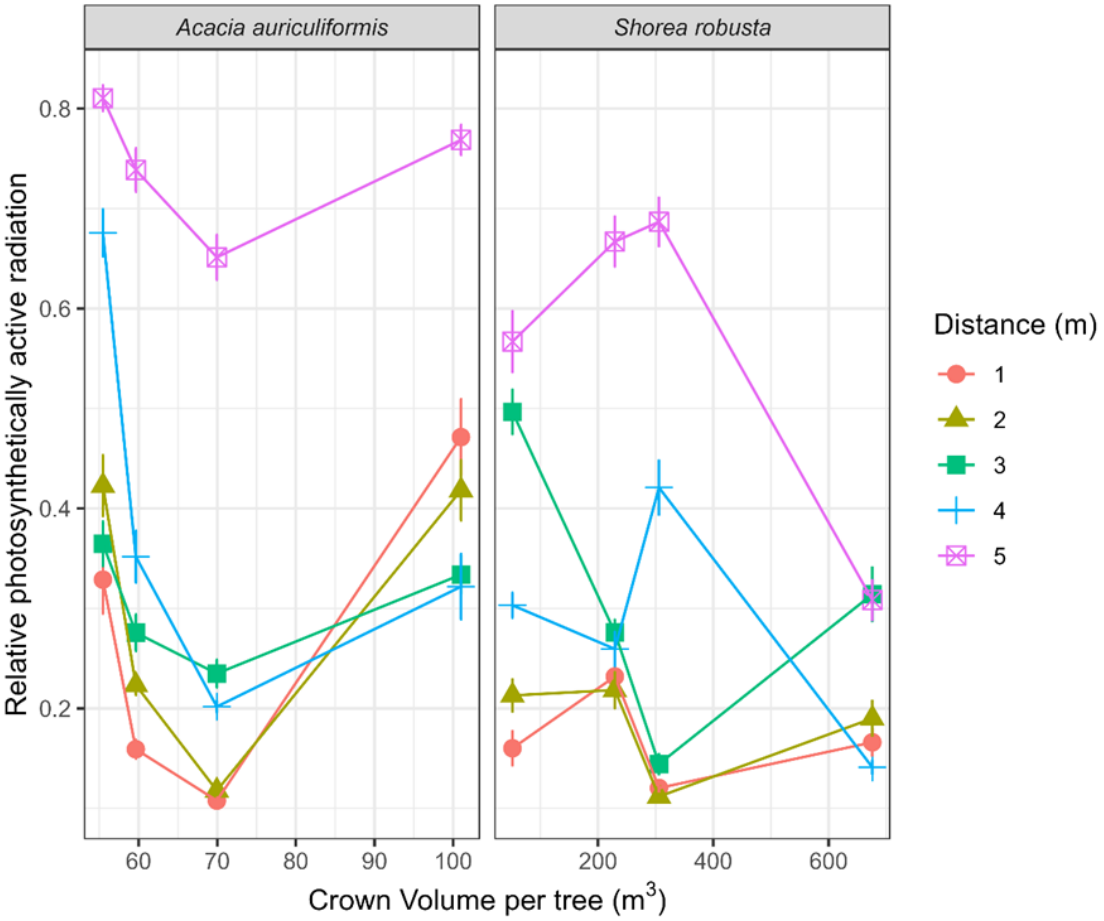

Figure 9. Relationship of RPAR to crown volume per tree at variable distance in *Shorea robusta* and *Acacia auriculiformis*, X-axis denotes the crown volume of trees, Y-axis denotes the RPAR, and five colors denote the distance (m) from ground

that, the average light environment of two examined stands was quite similar while some other stand variables were varied. Generally, it is believed that the canopy shape and size, significantly affect the light interception as well as the growth and development of understory crops in agroforestry practices (Horn 1971; Khan et al. 2004; Sinoquet et al. 2007). The above ground biomass is also positively effect on the light intensity of agroforestry stand. The mean RPAR of *Shorea robusta* with *Ananas comosus*; and *Acacia auriculiformis* with *Ananas comosus* in our study were 0.171 and 0.177 respectively.

Light availability is significantly altered in agroforestry systems (Rivest et al. 2009) and light interception is a driving variable for many key ecosystem processes in forests and agroforestry areas (Mariscal et al. 2004). In every agroforestry system, the tree canopy lessens the incident radiation for the crop (Dufour et al. 2013). The shade of the trees induces stress conditions for the harvest (Dufour et al. 2013). Lack of sufficient incident light boosted the changes in microclimate modification which hampers the potential growth and yield of crops under the trees in the agroforestry system (Alam et al. 2018). In the two study sites, the average height of *Ananas comosus* was quite similar because of the similar light interception of the two tree species. Rahaman et al. (2020) found 42 species of 26 families in natural *Shorea robusta* forest and 15 species of 13 families in *Acacia auriculiformis* plantations in the study area. Besides, Uddin et al. (2021) found 21 species of 18 families in the study area. More research trial of agroforestry system with other tree species found in the natural forest would be sought to contribute to the restoration process in the area.

Strong correlations ($P<0.01$) were found among the dbh, height, aboveground biomass, crown size, distance from individual trees etc. (Figure 4). It was found that the value of RPAR was not significant ($P>0.05$) among the four directions of individual trees in *Shorea robusta* while *Acacia auriculiformis* showed a significant difference ($P<0.001$) (Table 1). The average relative photosynthetically active radiation (RPAR) was found below 0.2 from the tree to 3 meters in the distance for *Shorea robusta in most of the cases.* In *Acacia auriculiformis*, the average RPAR was found below 0.2 from the tree to 2 meters in the distance. The understory light environment of a tree is affected by the canopy of the tree (Nicotra et al. 1999; Denslow & Guzman 2000; Montgomery & Chazdon 2001). Tree shading significantly reduced the amount of incoming photosynthetically active radiation (PAR) (Li et al. 2008). Crown structure and crown volume are essential determinants of light capture (Horn 1971; Khan et al. 2004; Duursma & Mäkelä 2007; Sinoquet et al. 2007).

In most cases, *Acacia auriculiformis* showed a higher value of average relative photosynthetically active radiation (RPAR) than the *Shorea robusta* because of having a lower crown volume. The crown shape and size of trees are responsible for this kind of light interception. It found that the crown shape of *Shorea robusta* was more than the *Acacia auriculiformis*, which was the cause of the light interception probably by *Shorea robusta* was more than *Acacia auriculiformis.* The total amount of light decreased with increasing crown volume. However, the *Acacia auriculiformis* is growing faster than *Shorea robusta* and the economic returns from *Acacia auriculiformis* agroforestry system is quicker. Because of the quick economic returns, people adjacent to Sal *(Shorea robusta)* forest desired *Acacia auriculiformis* as cover crop in Agroforestry. However, Nurunnahar et al. (2020) found various agroforestry systems with various trees *(Artocarpus heterophyllus*, *Areca catechu*, *Cocos nucifera*, *Swietenia macrophylla*, *Phoenix dactylifera*, *Moringa oleifera*, *Syzygium cumini*, *Borassus flabellifer*, *Azadirachta indica* etc.*)* and crops *(Oryza sativa*, *Colocasia esculenta*, *Curcuma longa*, *Kaempferia galangal*, *Musa paradisiaca*, *Solanum lycopersicum*, *Capsicum spp*., *Brassica oleracea*, etc.*)* in Bangladesh. So, to select the appropriate crop-combination, we need extensive research with various crops. The light environment of various trees should be identified and also measure the light demand of various agriculture crops.

CONCLUSION

In sustainable agroforestry practice, selecting crops and their composition is vital to get more yields. The effects of species, distance from the tree, above-ground biomass, and canopy size and shape were significant on RPAR for both *Shorea robusta* and *Acacia auriculiformis.* Although both species gave similar RPAR at the stand level, there were some differences between individual tree levels. It can be claimed that enough light can penetrate in both tree species (*Shorea robusta* and *Acacia auriculiformis*) in agroforestry stands explored. The results support us to get an idea about the light environment in the agroforestry system in relation to distance from trees. The results of this have implications on conservation of *S. robusta* cover in sal (*Shorea robusta*) forest if the species is considered a candidate tree species for a medium term rotation species in agroforestry practice in the area.

AUTHOR CONTRIBUTION

A.F.I. and N.I.K. designed the research, A.F.I. collected the data, A.F.I.

and N.I.K. analyzed the data, M.N.S. and A.F.I. wrote the manuscript. All authors revised and approved the manuscript.

ACKNOWLEDGEMENTS

The authors are grateful to Forestry and Wood Technology Discipline, Khulna University, Bangladesh for providing logistic support in field data acquisition. This research did not receive any specific grant from any aid agencies.

CONFLICT OF INTEREST

There is no competing interests.

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