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Above- and below-ground interactions in teak-barley agroforestry system in the Bundelkhand region of Central India

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ABSTRACT: *The present study was aimed to optimize productivity of teak (Tectona grandis L.f.) based agroforestry system by evaluating some above- and below-ground interactions and their effects on growth and yield of intercropped barley (Hordeum vulgare L.). Sixteen treatment combinations comprising of four distances (D1- 1 m, D2- 2 m, D3- 3 m and D4- 4 m) away from tree-base and four directions (East, West, North and South) were evaluated using Factorial Randomized Block Design with three replications. Data on light interception (Hz), plant height (cm), chlorophyll content (SPAD value), soil moisture (%) and grain yield (g m^{-2}) were collected and analysed. Light interception reached at its peak at 12.00 noon and lowest at 5.00 pm. At its peak, highest light interception (1193.8 Hz) was recorded in East direction at D4 and lowest (949.0 Hz) in the West at D1. Light interception in West and North directions was statistically lower than other directions. Light interception increased with increase in distance from the tree-stem. At 30 days after sowing (DAS), tallest plants were observed in West direction (23.08 cm) and shortest in the East (20.85 cm). The plant height at D1, D2 and D4 were statistically at par. At 30 DAS, lowest chlorophyll content (25.9) was observed in East direction at D4, whereas highest at 30 DAS in the West at D1 (31.5). At 90 DAS, significantly higher chlorophyll content was recorded in West direction and lowest in the South. Plants nearer to tree-stem showed high chlorophyll content. At 90 DAS, West and North directions recorded comparatively higher soil moisture, and among distances, it was recorded highest at D1. Among directions, highest grain yield was observed in East direction (210.1 g m^{-2}) and lowest in the South (206.1 g m^{-2}). The grain yield increased with distance from the tree trunk and significantly higher grain yield (4.68%) was recorded at D4 as compared to D1. From the findings, it can be concluded that the teak-barley agroforestry system, despite some significant above- and below-ground interactions affecting intercrop yield, may be a potential land-use system for adoption in the semi-arid region.*

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1. INTRODUCTION

Agriculture sector provides livelihood to about 42.8% of India's population (Government of India-Ministry of Finance, 2021), but Indian agriculture is undergoing a heavy stress as average land holdings is decreasing day by day. The per capita availability of agricultural land in India is 0.12 ha, whereas world per capita agriculture land is 0.29 ha. Additionally, farmers are also facing a big challenge from climate change effects as the Indian agriculture is highly dependent on variations of weather. In recent days, agriculture sector has become less attractive among farming community due to less remuneration and involvement of high risk because of change in climatic conditions (Dhyani *et al*., 2016; Ram *et al*., 2016). Hence, a serious threat is being predicted for increasing food grain production and meeting the food, fibre, fuel and fodder requirements of ever-growing population (Ram *et al*., 2016). However, the role of agroforestry in climate smart agriculture has raised considerable expectations since last few decades.

Agroforestry is the best means of sustainable agriculture, which not only meets our basic needs of food, fuel, fodder, fruit, etc. but also helps in providing better ecosystems to living being. Agroforestry is a low-input system which combines trees with crops in various combinations or sequences. It is an alternative to intensive cropping systems, which rely on large inputs of manufactured fertilizers and other external inputs to sustain production system. Agroforestry has the potential to reduce risks through diversification of a variety of products, including food, fuelwood and animal fodder (Tewari *et al*., 2018). It has also been identified as a potential option to mitigate climate change through creating and enhancing carbon sinks by capturing carbon from the atmosphere and storing it in biomass and soil (Dhyani *et al*., 2016). Other perceived

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benefits include enhanced nutrient and water use efficiencies, reduced nutrient leaching and improved soil physical and biological properties. In commercial agroforestry systems, trees are planted in such a row-pattern that modern farm machinery techniques can efficiently be used in tree alleys for growing of crops (Quinkenstein *et al*., 2009; Tsonkova *et al*., 2012; Nerlich *et al*., 2013).

The Bundelkhand region of central India is characterized by semi-arid climate, undulating topography and shallow soils. Mean annual rainfall in this region is about 750 mm and unevenly distributed throughout the year. About 85% of total rainfall is received during July to September and 15% is distributed in remaining months of the year. Rainfall variability and water scarcity continue to hamper food and income security of smallholder farming systems in poverty-affected region. The region is highly prone to the impacts of climatic variabilities. Due to erratic behavior of climatic conditions, the farmers of the region are facing crop failure very frequently (Dev *et al*., 2020). Under such circumstances, agroforestry interventions may show potential to support livelihood of the farmers (Dev *et al*., 2017).

To harness the maximum benefits of agroforestry, it is important to understand interactions among components of the systems. Interaction is defined as the effect of one component of a system on the performance of another component and/ or the overall system. The negative and positive interactions determine the overall effect in a given agroforestry system (Ndolie *et al*., 2017). Understanding the scientific basis of tree-crop interactions in agroforestry helps in devising appropriate ways to increase the productivity of the system. Ecological interactions between trees and crops need to be examined in terms of utilization of above- and below-ground resources. Suryanto *et al*. (2014) reported that with increasing the shade level, physiological response of the associated crop decreased.

Tectona grandis L.f., *Acacia nilotica* L., *Albizia procera* (Roxb.) Benth., *Azadirachta indica* A. Juss., *Dalbergia sissoo* Roxb. ex DC, *Melia* spp, etc. are some of the potential forest tree species which are suitable for integration in different agroforestry systems in Bundelkhand region. Teak (*T. grandis*) is one of the most valuable timber tree species in the world and also found in Bundelkhand region. This species can be a best agroforestry species for harsh climatic conditions of Bundelkhand region. The prominent crops grown in region are *Sorghum bicolor* (L.) Moench (sorghum), *Cajanus cajan* (L.) Millsp. (pigeonpea), *Vigna mungo* (L.) Hepper (urdbean), *Vigna radiata* (L.) R. Wilczek (mungbean), *Sesamum indicum* L. (sesame), *Glycine max* (L.) Merr. (soybean) and *Oryza sativa* L. (rice) during *kharif* and *Triticum arestivum* L. (wheat), *Hordeum vulgare* L. (barley), *Cicer arietinum* L. (chickpea), *Pisum sativum* L. (field pea), *Lens culinaris* Medik (lentil), *Linum usitatissimum* Linn. (linseed) and *Brassica* spp. (mustard) during *rabi* season. Barley (*H. vulgare*) is one of the low water requiring *rabi* crops which is suitable for water scare areas of Bundelkhand region.

Keeping in view the importance and suitability of teak and barley in harsh climatic conditions of the Bundelkhand region, their interaction studies were undertaken with the objective to optimize the productivity of teak-barley based agroforestry system.

2. MATERIALS AND METHODS

Site description and experimental details

The study on tree-crop interaction in teak-barley agroforestry system was carried out at research farm of ICAR-Central Agroforestry Research Institute (25º 30′ - 25º 32′ N and 78º 32′ - 78º 34′ E, at altitude of 272 m above mean sea level), Jhansi, Uttar Pradesh, India during *rabi* season of 2019-20. The average annual rainfall of the study site is 867 mm and most of the rainfall occurs during monsoon season. Mean monthly maximum temperature ranges from 23.5 (January) to 47.4ºC (June), and mean monthly minimum temperature ranges from 4.1 (December) to 27.2ºC (June), where May and June are the hottest months (Dev *et al*., 2020). The soil of the experimental site was low in fertility and inter-mixed red and black soil group of Bundelkhand region of Uttar Pradesh covered under the order of Alfisol. The soil was shallow, gravelly and light textured. The initial soil pH (1:2.5, soil: solution ratio), electrical conductivity (dS m^{-1}) and soil organic carbon (%) were 6.79, 0.091 and 0.39, respectively. The experimental soil was poor in available nitrogen (135 kg ha^{-1}), 0.5N $NaHCO_3$ extractable phosphorus (7.2 kg ha^{-1}) and medium in 1.0 N NH_4OAC exchangeable potassium (145 kg ha^{-1}).

Teak was planted in the year 2014 at 9 m row to row and 4 m plant to plant distances. Sixteen treatment combinations comprising of four distances (D1- 1, D2- 2, D3- 3 and D4- 4 m) away from tree and four directions (East, West, North and South) were studied using Factorial Randomized Block Design with three replications. The average height and DBH of teak plants ranged from 4.09 to 4.85 m and from 9.89 to 11.00 cm, respectively. Observations on crop growth parameters were recorded from West, North-West, North, North-East, East, South-East, South, South-West directions from the tree trunk. The average data of four different directions were recorded as East (East, North-East and South-East); West (West, North-West and South-West); North (North, North-East and North-West) and South

(South, South-East and South-West). Teak trees were pruned up to 2.5 m height from ground level.

Observations

Light interception in barley crop was measured by Line Quantum Sensor (Model LI-CORLI-191R). The sensor was kept just above the barley crop at different distances and directions. Observations on light interception were taken at 30 days after sowing (DAS), 60 DAS, 90 DAS and at harvest during 9.00 am to 5.00 pm at hourly intervals, and the values were expressed in Hz. Leaf chlorophyll value was monitored with chlorophyll meter (SPAD-502, Soil-Plant Analysis Development Section, Minolta Camera Co.) at the midpoint of the second fully expanded leaf with 10 replications in each plot at 30, 60 and 90 DAS. Five plants at each distance of all directions were randomly selected and marked for recording plant height. The height of barley was measured from the base of plant at ground surface to the tip of the tallest leaf at 30, 60 and 90 DAS. Soil moisture content (%) of plough layer soil at different distances and directions from teak tree was measured using Thermo Gravimetric method. The soil moisture content was calculated using formula given below:

$$\text{Soil moisture (\%)} = \frac{\text{Fresh weight (g) of soil - Dry weight (g) of soil}}{\text{Dry weight (g) of soil}} \times 100$$

For estimating grain and straw yields (g), plants from 50 cm^2 area were harvested at physiological maturity at different distances and directions, sun-dried for three days in the field and then the total biomass yield was recorded and expressed in g m^{-2}. After threshing, cleaning and drying, the grain yield was recorded and reported at 14% moisture content.

Statistical analysis

The data were analyzed as per the procedure of Analysis of Variance of a factorial randomized block design and significance tested by "F" test (Gomez and Gomez, 1984). Standard Error of Means (+) and Least Significant Difference (LSD) at 5% level of significance were worked out for each parameter.

3. RESULTS AND DISCUSSION

Light interception (Hz)

Data on light interception by barley crop below teak canopy at different distances and directions are presented in Table 1 and 2. At 9.00 am, lowest light interception was recorded in West and highest in South direction which was found at par with East direction. Light interception reached at its peak at 12.00 noon and lowest at 5.00 pm. At hourly interval, up to 1.00 pm, light interception in East and South directions was comparatively higher as compared to other two directions. But at 3.00 pm and onwards, no clear trend was observed. At 30 DAS, significantly higher light interception (148.2 Hz) was recorded in East and lowest in the West direction (140.0 Hz); however, light interception at different distances remained at par with each other. At 60 DAS, relatively higher light interception (767.5 Hz) was recorded in South which was statistically at par with the East direction. Light interception in West and North directions was statistically lower than that recorded from other directions. Almost similar trend was observed at harvest stage. Increase in light interception with increase in distance from tree stem was noticed. No interactive effect of direction and distance was found significant at all growth stages of barley. The shade was moving nearer and far from

Table 1. Light interception (Hz) at different crop growth stages of barley in teak-based agroforestry system.

Treatment	30 DAS*	60 DAS	90 DAS	At harvest
Directions				
East	148.2	751.6	849.4	1288.1
West	140.0	707.2	840.2	1219.7
North	144.1	744.4	827.1	1214.4
South	145.6	767.5	858.9	1301.4
S. Em. (±)	1.8	9.2	10.5	15.6
$LSD_{0.05}$	5.2	26.6	NS	45.2
Distance from tree base				
D1**	144.3	700.2	795.7	1247.3
D2	144.6	724.2	816.5	1261.7
D3	143.6	763.7	869.7	1241.9
D4	145.3	782.7	893.6	1272.7
S. Em. (±)	1.8	9.2	10.5	15.6
$LSD_{0.05}$	NS	26.6	30.5	NS

*DAS- Days after sowing; **D1- 1 m, D2- 2 m, D3- 3 m, D4- 4 m tree stem with the movement of sun. Variation in light interception is one of the key interactions between trees and crops. Tree reduces the amount of sunlight reaching soil and crop through shading. Light capture is influenced by both environmental and plant factors such as tree leaf area, leaf phenology, crown structure and crown management. It is also reported that trees in agroforestry systems modify micro-climate for annual crops (Ong and Leakey, 1999). Compared to an open environment, the modified micro-climate under trees is characterized by reduced solar radiation, a more moderate temperature regime, higher humidity, lower rates of crop transpiration and higher soil moisture levels (Singh *et al*., 2012).

Plant height (cm) and chlorophyll content (SPAD value)

At 30 DAS, comparatively taller plants (23.08 cm) were observed in West direction and shortest (20.85 cm) in the East (Figure 1). The plant height at D1, D2 and D4 were statistically at par with each other. No significant difference in height was recorded at 60 DAS in different directions and distances from the tree. However, at 90 DAS and at harvest, significantly taller plants were observed at D1, which might be due to competition for light in shade conditions (Thakur *et al*., 2019). The data on chlorophyll content in barley leaves at different directions and distances are presented in Figure 2 and Table 3. At 30 DAS, lowest chlorophyll content (25.9) was observed in East direction at D4 and highest in the West at D1 (31.5). At 90 DAS, minimum chlorophyll content was recorded in South and maximum in West direction. Plants nearer to tree showed higher chlorophyll content. The variation in chlorophyll content in barley crop at different distances might be due to the shade

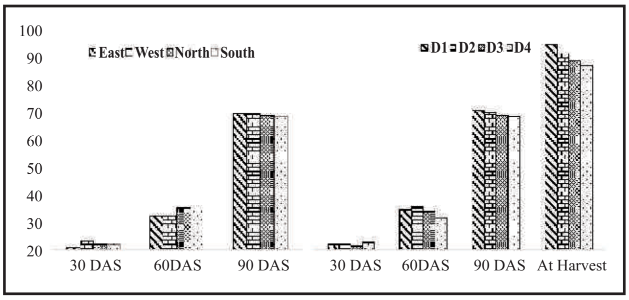

Fig. 1. Individual effects of direction and distance from teak on height (cm) of barley plant.

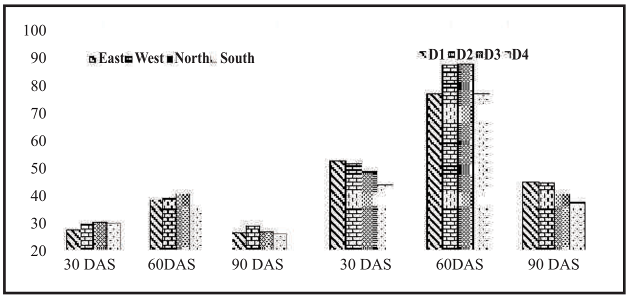

Fig. 2. Individual effects of direction and distance from teak on chlorophyll content (SPAD value) in barley.

Table 2. Interactive effect (direction × distance) on light interception (Hz) at different stages of crop growth of barley in teak-based agroforestry system.

Treatment combination	30 DAS*	60 DAS	90 DAS	At harvest
ED1**	145.3	700.4	800.4	1274.7
ED2	147.7	740.1	808.4	1308.4
ED3	149.4	771.7	885.1	1271.9
ED4	150.3	794.3	903.6	1297.2
WD1	142.0	671.3	811.6	1241.0
WD2	140.3	701.4	786.6	1177.9
WD3	139.0	711.0	879.6	1225.7
WD4	138.7	745.0	883.0	1234.2
ND1	144.6	696.7	760.4	1196.9
ND2	144.8	699.8	826.2	1231.7
ND3	141.3	788.4	841.8	1169.9
ND4	145.7	792.9	879.8	1259.3
SD1	145.1	732.4	810.3	1276.4
SD2	145.8	755.5	844.8	1328.9
SD3	144.8	783.6	872.3	1300.1
SD4	146.5	798.6	908.1	1300.0
S. Em. (±)	3.6	18.3	21.0	31.1
$LSD_{0.05}$	NS	NS	NS	NS

*DAS- Days after sowing; **E- East, W- West, N- North, S- South; D1- 1 m, D2- 2 m, D3- 3 m, D4- 4 m effect of teak tree. Similar variation in chlorophyll content due to shading was also reported by Mauro *et al*. (2011) and Chen *et al*. (2019).

Soil moisture (%)

At the time of sowing, highest soil moisture content (12.92%) was observed in West and lowest (11.88%) in the East direction (Figure 3 and Table 4). The soil moisture at D2 was significantly higher. At 30 DAS, highest soil moisture content was observed at D1. At 60 DAS, North direction recorded high soil moisture content, and among distances, D1, D2 recorded higher soil moisture content as compared to D3 and D4. At 90 DAS, West and North directions recorded comparatively higher soil moisture content, and among distances, it was recorded highest at D1. Similar variation has also been reported by Godefroid and Koedam (2010). The effect of tree on soil moisture seems to be variable depending on the ecosystem (Vetaas, 1992), so it should not be generalized that trees increase or decrease moisture availability below canopies (Gea-Izquierdo *et al*., 2009). In present study, variation in soil moisture content in different direction and distances were recorded. More or less similar results have also been reported by some researchers (Joffre and Rambal, 1993; Cubera and Moreno, 2007).

Grain yield (g m^{-2})

Among the directions, highest grain yield (210.1 g m^{-2}) was observed in East direction and lowest (206.1 g m^{-2}) in the South (Figure 4). The grain yield increased with distance from the tree trunk and was significantly higher (212.2 g m^{-2}) at D4 and D1 (202.8 g m^{-2}). Understory crop yield is determined by the intercepted available light, and the efficiency of converting the intercepted light into photosynthates (Gao *et al*., 2013; Chen *et al*., 2019; Qiao *et al*., 2019). Peng *et al*. (2009) reported a decrease of 38 and 29% in the yield of maize and soybean, respectively in tree-based intercropping system in China. However, in our study, reduction in crop yield was minimum due to better pruning management and straight bole of the teak tree. The interaction effect of direction and distance was also found non-significant with respect to crop yield.

4. CONCLUSION

Light interception, growth, soil moisture and yield of the associated barley crop varied in different directions and distances from the tree trunk of the teak. In general, growth and yield of the barley increased with increase in the distance from the tree trunk and among various directions, crop performed better in East. However, tree-crop interactions depend on the various associated factors;

Table 3. Interactive effect (direction × distance) on plant height (cm) and chlorophyll (SPAD value) at different stages of crop growth of barley in teak-based agroforestry system.

Treatment combination	Plant height (cm)				Chlorophyll (SPAD value)		
	30 DAS*	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	90 DAS
ED1**	20.5	34.0	72.3	94.5	29.0	36.5	27.0
ED2	20.7	33.4	69.2	90.2	28.4	40.1	26.8
ED3	20.7	32.7	69.1	91.1	27.1	42.6	26.7
ED4	21.5	29.2	68.1	88.5	25.9	36.8	24.8
WD1	23.6	33.7	70.9	92.1	31.5	39.1	30.2
WD2	22.9	33.9	70.3	88.4	30.8	40.9	29.9
WD3	22.5	32.0	69.0	85.9	28.5	38.5	26.8
WD4	23.3	29.7	68.1	84.6	27.5	38.7	28.9
ND1	20.5	35.3	68.3	97.0	30.9	40.1	26.3
ND2	21.3	36.9	69.9	92.7	31.3	43.1	28.6
ND3	21.5	34.3	69.1	87.9	30.5	40.6	27.4
ND4	23.7	34.8	67.3	86.2	28.1	40.2	24.2
SD1	23.2	34.9	70.5	93.2	30.5	37.4	28.4
SD2	22.8	37.0	68.8	91.6	29.8	42.2	26.0
SD3	20.5	34.8	66.3	88.3	30.4	45.0	25.3
SD4	21.5	32.6	68.4	87.2	28.8	37.5	24.1
S. Em. (±)	0.40	0.64	1.39	1.66	0.67	0.60	0.50
$LSD_{0.05}$	1.17	NS	NS	NS	NS	1.74	1.45

*DAS- Days after sowing; **E- East, W- West, N- North, S- South; D1- 1 m, D2- 2 m, D3- 3 m, D4- 4 m

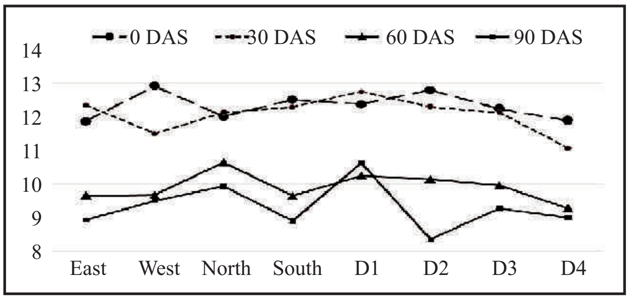

Fig. 3. Individual effects of distance and direction from teak on soil moisture content (%).

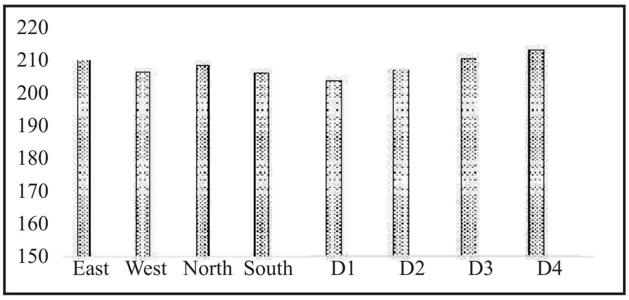

Fig. 4. Individual effects of direction and distance from teak on grain yield (g m^{-2}) of barley.

Table 4. Interactive effect (direction × distance) on soil moisture content (%) and crop yield (g m^{-2}) of barley in teak-based agroforestry system.

Treatment combination	Soil moisture content (%)			Crop yield (g m^{-2})
	30 DAS*	60 DAS	90 DAS	
ED1**	12.5	11.1	10.1	206.3
ED2	13.0	10.6	7.8	207.0
ED3	12.6	10.2	8.9	211.1
ED4	11.3	6.8	8.9	216.0
WD1	14.1	10.9	10.4	201.7
WD2	11.4	8.1	8.0	206.4
WD3	10.9	10.2	10.0	208.5
WD4	9.6	9.5	9.6	209.1
ND1	11.9	10.3	11.3	204.0
ND2	12.1	11.6	9.5	207.4
ND3	12.5	11.5	9.4	211.1
ND4	12.0	9.2	9.5	210.8
SD1	12.6	8.7	10.7	199.0
SD2	12.7	10.3	8.1	204.2
SD3	12.5	8.0	8.8	208.6
SD4	11.4	11.6	8.0	212.8
S. Em. (±)	0.30	0.24	0.23	1.86
$LSD_{0.05}$	0.15	0.71	0.67	NS

*DAS- Days after sowing; **E- East, W- West, N- North, S- South; D1- 1 m, D2- 2 m, D3- 3 m, D4- 4 m

hence, this needs to be studied further at different age of the tree component. The findings revealed that in the harsh climatic conditions of the Bundelkhand region, teak-barley based agroforestry system may be a potential land-use system for adoption .

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