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Research Article

Effect of Tree-Crop Interactions in *Melia dubia*-Wheat Agroforestry System on Light Interception, Growth and Yield of Wheat in Bundelkhand Region of Central India

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ABSTRACT

Agroforestry is an ecologically sustainable land use option that enhances system yield by combining food crops with tree crops or livestock on the same piece of land. The present study was aimed to optimize productivity of Malabar neem (*Melia dubia*) based agroforestry system by evaluating the above- and below-ground interactions and their effect on growth and yield of intercropped wheat (*Triticum aestivum* L.). Eight treatment combinations comprising of four directions (North, South, East and West) and two distances (D1-1 m and D2-2 m) away from tree base were evaluated using a factorial randomized block design with three replications. Observations on light intensity (Hz), plant height (cm), dry matter accumulation (g m^{-2}), chlorophyll content (SPAD value), grain yield (g m^{-2}) and soil moisture content (%) were taken and statistically analysed. The light intensity reached its peak at 12.00 noon and recorded lowest at 5.00 pm. Amongst different treatment combinations, highest light intensity was recorded at 2.0 m distance from tree base in the South direction of the tree. Likewise, highest dry matter accumulation in wheat was observed at 2.0 m distance in the South direction. However, no clear trend of the direction was observed on the SPAD value in wheat and soil moisture content, but these values were observed higher nearer (D1) to tree base. The above- (light, space) and below-ground (soil moisture, nutrient) interactions between *Melia* and associated wheat crop resulted in higher grain yield in the East (157.5 g m^{-2}) and South direction (155.6 g m^{-2}). The grain yield of wheat at 2.0 m distance was observed 10.92% higher than the 1.0 m distance from tree base. The findings suggest that wheat can successfully be grown under *Melia* based agroforestry system.

Key words: Agroforestry, Light interception, Malabar neem, Tree-crop interaction

Introduction

Traditionally, before the intensification of agriculture, trees were commonly found on farmlands, playing a vital role in the ecosystem. However, ushering the Green Revolution in 1960s with introduction of high-yielding, semi-dwarf, and input (i.e., irrigation and chemical fertilizers) responsive crop varieties led to significant changes in farming practices (Debnath *et al*., 2023). While this period is often cherished for achieving food security for many nations, including India, it also underwent the large-scale removal of trees from agricultural fields to facilitate farm mechanization. This shift had eventually exaggerated loss of biodiversity, decline in ecosystem services, and

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reduction in the carbon storage capacity of agroecosystems in India. In the face of global challenges such as climate change, increasing chemical use in agriculture, and declining system productivity, there has been a growing recognition of the need for sustainable land-use management practices. Approaches like agroforestry, integrated farming systems, natural farming, and organic farming have gained prominence as they not only enhance biodiversity but also increase the resilience of agricultural production systems to climate fluctuations, offering a sustainable path forward for the future of agriculture (Ram *et al*., 2023).

Agroforestry (AF) provides various ecosystem services, including food production, biodiversity conservation (Ram *et al*., 2023), soil enrichment (Udawatta *et al*., 2008), carbon sequestration (Dhyani *et al*., 2016), and efficient resource use (Zhang *et al*., 2018). It also plays an important role in offering other ecological services like reducing soil erosion (Ram *et al*., 2022), water erosion etc. (Branca *et al*., 2013). In agroforestry systems, trees and agricultural crops inevitably compete for resources such as sunlight, nutrients, and water. This competition can be categorized into above-ground (for sunlight) and below-ground (for nutrients and water) interactions (Upadhyaya *et al*., 2021; Zhou *et al*., 2014). Generally, the perennial components, such as trees, have a larger canopy and a more robust root system compared to the understorey crops (Yang *et al*., 2023). Despite this competition, trees play a crucial role in mitigating extreme weather events and creating a more stable micro-climate for the understorey crops. The effects of resource sharing in agroforestry systems can be either complementary or competitive, depending on the species involved, their growth patterns, and the prevailing climatic conditions.

Fast-growing tree species are increasingly promoted in agroforestry to enhance food security, livelihood sustainability, and environmental protection while also developing highly productive land-use systems that can reduce the impacts of climate change. Malabar neem (*Melia dubia*) is one such fast-growing tree species widely cultivated in the tropical and subtropical regions of India, except in high altitudes (Kumar *et al*., 2022). It is primarily used in the pulpwood, plywood, and timber industries. Farmers can plant it on their fields with varying spacing, depending on land availability, irrigation facilities, and the type of intercrops. Recent report (Chavan *et al*., 2022) suggests that intercropping in *Melia dubia* is highly successful in initial years of plantation. Wheat (*Triticum aestivum* L.), an important cereal crop of the *rabi* season in the Bundelkhand region of Central India, is one such intercrop. However, there is limited information on the interactions between *Melia dubia* and wheat on a spatio-temporal scale, especially in semi-arid conditions. Therefore, this study was conducted to understand the above-ground and below-ground interactions between *Melia dubia* and wheat to improve agroforestry practices in semi-arid regions.

Materials and Methods

Study site, climate and soil

The present study was conducted within a *Melia*-wheat agroforestry system located at ICAR-Central Agroforestry Research Institute in Jhansi, Uttar Pradesh, India (25°30′-25°32′ N; 78°32′-78°34′ E; at 272 m above mean sea level) during the *rabi* season of 2019-20. The average annual rainfall in the study area is 867 mm, with 70-80% occurring during the monsoon season. The mean monthly minimum temperature ranges from 4.1°C in December to 27.2°C in June, while the mean monthly maximum temperature ranges from 23.5°C in January to 47.4°C in June, with May and June being the hottest months (Upadhyaya *et al*., 2021).

The soil at the experimental field was a mixture of black and red soil (*Alfisol*) with a heavy texture. Initial soil analysis (0-15 cm depth) showed a pH of 7.43 (1:2.5 soil to water ratio, Jackson, 1958), electrical conductivity of 0.101 dS m^{-1} (1:2.5 soil to water ratio, Richards, 1954), and soil organic carbon content of 0.43% (Walkley and Black, 1934). The soil was deficient in available nitrogen (182 kg ha^{-1}), low in available phosphorus (8.8 kg ha^{-1}), and medium in available potassium (163 kg ha^{-1}).

Experimental details

Melia trees were planted in 2016 at the research farm with spacing of 5 (inter-row) × 4 (intra-row)

m. The study involved eight treatment combinations, consisting of four directions (East, West, North, and South) and two distances from the tree base (D1- 1 meter and D2- 2 meter). A factorial randomized block design (FRBD) with three replications was employed. The average height and diameter at breast height (DBH) of the Melia plants ranged from 9.55 to 10.75 m and 145.2 to 156.3 mm, respectively. The wheat crop (variety HD 2967) was sown on 20th November, 2019 at 22.5 cm line to line distance. Recommended package of practices were followed for cultivating the wheat crop in *Melia dubia*-based agroforestry system.

Observations

Growth parameters of wheat were recorded from eight directions relative to the tree trunk: West, North-West, North, North-East, East, South-East, South, and South-West. Data from the four main directions were averaged as follows: 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). During the crop growing season, *Melia* trees were pruned to 50%. Light intensity over the wheat crop in the *Melia*-based system was measured using a Line Quantum Sensor (LI-COR LI-191R). The sensor was placed just above the wheat crop at various distances and directions. Observations on light intensity were taken at 30, 60, and 90 days after sowing (DAS) and at harvest, from 9:00 am to 5:00 pm at hourly intervals. The data were presented in Hz.

Leaf chlorophyll content was monitored using a chlorophyll meter (SPAD-502, Soil-Plant Analysis Development Section, Minolta Camera Co.) by recording SPAD values at the mid-point of the second fully expanded leaf, on one side of the midrib, approximately one-third of the way down from the leaf tip on the main stem. Ten replications were taken in each plot at 30, 60, and 90 DAS. Five wheat plants at each distance and direction were randomly selected and marked for measuring plant height. Height was measured from the base of the plant at the ground surface to the tip of the tallest leaf at 30, 60, and 90 DAS.

For dry matter accumulation, plants from a 50 cm row length were harvested at various growth stages and distances. Harvested plants were sun-dried for 2-3 days and then oven-dried at 60±2°C for 24 h. The dry weight was recorded in grams per square meter (g/m²) at 30, 60, and 90 DAS, and at harvest. Soil moisture content (%) of plough layer soil at different distance and direction from *Melia* tree was measured by using thermo gravimetric method. The soil moisture content was calculated using following formula:

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

For yield estimation (grain and straw) of wheat in the *Melia*-based agroforestry system, plants from a 50 cm row length were harvested at physiological maturity from various distances and directions. The plants were sun-dried for three days in the field, and the total biomass yield was recorded and expressed in grams per square meter (g/m²). After threshing, cleaning, and drying, the grain yield was recorded and reported at 14% moisture content.

Statistical analysis

Data related to each parameter were analyzed using analysis of variance (ANOVA) as per the procedure for a factorial randomized block design (FRBD), with significance tested by the F-test (Gomez and Gomez, 1984). The standard error of means (SEm ±) and least significant difference (LSD) at the 5% level were calculated for each parameter.

Results and Discussion

Light intensity

The averaged data of light intensity with respect to time interval showed that irrespective of direction, light intensity beneath the tree canopy increased with the advancement of the day time and reached maximum (899.5 Hz) at 2 pm in East direction, thereafter it started to decline and recorded lowest (172.9 Hz) in North direction at 5 pm of the day (Table 1). At 9 am, lowest light intensity (361.4 Hz) was recorded in West and highest in East direction (497.1 Hz). However, no clear trend of light intensity was observed with respect to different directions. On the other hand, irrespective of directions,

Table 1. Effect of individual factor (distance and direction) of *Melia* tree and their interaction on light intensity (Hz) during day time in wheat

Treatment	Day time								
	9.00 am	10.00 am	11.00 am	12.00 noon	13.00 pm	14.00 pm	15.00 pm	16.00 pm	17.00 pm
East (E)	497.1	741.9	749.8	653.7	750.0	749.8	402.7	412.3	180.4
West (W)	361.4	501.9	690.0	666.6	695.3	768.6	439.4	419.4	181.1
North (N)	433.3	605.6	733.3	726.1	687.3	723.4	441.8	416.4	172.9
South (S)	443.8	614.3	779.6	817.8	796.5	792.6	492.1	452.1	179.7
SEm±	8.4	12.0	14.5	13.3	14.1	14.8	8.3	8.0	3.5
$LSD_{0.05}$	25.8	36.7	44.3	40.8	43.0	45.3	25.5	24.6	10.7
D1	418.4	602.4	712.1	619.3	664.4	726.6	428.3	399.0	171.8
D2	449.3	629.4	772.1	752.7	766.6	754.8	413.1	414.7	183.7
SEm±	6.0	8.5	10.2	9.4	9.9	10.5	5.9	5.7	2.5
$LSD_{0.05}$	18.2	26.0	31.3	28.8	30.4	NS	NS	NS	7.6
ED1	471.8	707.0	858.5	672.3	714.8	636.5	385.3	390.0	167.3
ED2	522.5	776.8	938.3	816.0	837.5	677.5	343.8	348.5	168.3
WD1	356.5	517.5	593.8	530.3	680.8	783.0	444.0	414.3	174.5
WD2	366.3	486.3	608.5	596.3	767.0	902.3	437.8	496.3	211.8
ND1	418.5	582.5	633.5	524.3	500.5	679.0	389.3	376.8	158.3
ND2	448.0	628.8	694.3	653.0	546.3	560.0	343.8	348.8	167.0
SD1	427.0	602.5	762.8	750.3	761.5	808.0	494.5	415.0	187.3
SD2	460.5	626.0	847.3	945.5	915.5	879.5	527.3	465.3	187.8
SEm±	11.9	17.0	20.4	18.8	19.9	20.9	11.8	11.4	4.9
$LSD_{0.05}$	NS	NS	NS	57.7	NS	64.1	36.1	34.8	15.1

significantly higher light intensity was recorded in crop grown at 2 m distance from the tree base during 9 am to 1 pm and at 5 pm but remained at par between 2 to 4 pm.

The two-way interaction between direction and distance showed variable results in term of light intensity (Table 1). It was not comparable between 9 to 11 am, however at 12 noon, it was recorded significantly higher in South direction at 2 m distance from the tree. At 2 pm, the maximum light intensity was recorded in crop growing at 2 m distance in West direction which was at par with the value recorded from 2 m distance in South direction. At 3 pm, maximum intensity was recorded in South direction, and at 4pm, it was found maximum at 2 m distance in West, followed by 2 m distance in South direction. At 5 pm, significantly higher light intensity was recorded in wheat crop grown in West direction at 2 m distance from *Melia* tree. At hourly interval, no clear trend of light intensity was observed in directions and distances due to pruning management and clear bole of the Melia.

Data on effect of individual factors (distances and directions) on light intensity in wheat crop at 30, 60, 90 DAS and at harvest stages are presented in Table 2. At all growth stages, significantly higher light intensity was recorded in crop growing in South direction, barring few exception. On the other hand, distance from tree bole also showed significant effect on light intensity. It was recorded significantly higher at 2 m distance from the tree bole when compared with the values recorded beneath the tree canopy of *Melia* at all growth stage. The two-way interaction between direction and distance did not show any significant effect on light intensity (Table 2), hence could not be compared. However, it was quite higher in South direction as well as at 2 m distance from the tree bole.

The shade was moving nearer and far from tree stem with sun movement. Light is one of key interaction 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,

Table 2. Effect of individual factor (distance and direction) of *Melia* tree and their interaction on light intensity (Hz) at different growth stages in wheat

Treatment	30 DAS	60 DAS	90 DAS	At Harvest
East (E)	493.2	516.5	569.3	620.9
West (W)	492.6	514.0	524.8	622.8
North (N)	482.1	533.5	533.4	631.8
South (S)	524.0	587.9	565.0	676.2
SEm±	9.6	10.3	10.7	12.2
$LSD_{0.05}$	29.5	31.6	32.7	37.3
D1	472.7	516.1	529.2	589.6
D2	511.1	538.6	565.4	667.7
SEm±	6.8	7.3	7.5	8.6
$LSD_{0.05}$	20.9	22.4	23.1	26.4
ED1	464.9	545.1	591.8	621.9
ED2	514.9	589.9	637.6	670.6
WD1	475.3	464.0	497.7	560.6
WD2	517.7	467.0	550.2	630.6
ND1	422.2	461.9	475.2	535.1
ND2	416.4	442.0	497.0	595.6
SD1	528.3	593.4	552.2	641.0
SD2	595.6	655.6	576.7	774.2
SEm±	13.6	14.6	15.1	17.2
$LSD_{0.05}$	NS	NS	NS	NS

tree phenology, crown structure and management. Variation in light interception is one of the key interactions between trees and crops. It is also reported that trees in agroforestry systems modify micro-climate for annual crops (Shi *et al.*, 2018). Compared to an open environment, the modified microclimate 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 and dry matter accumulation

Effect of directions on height of wheat plants was found significant at all growth stages, except at 90 DAS (Fig. 1). At harvest, the maximum plant

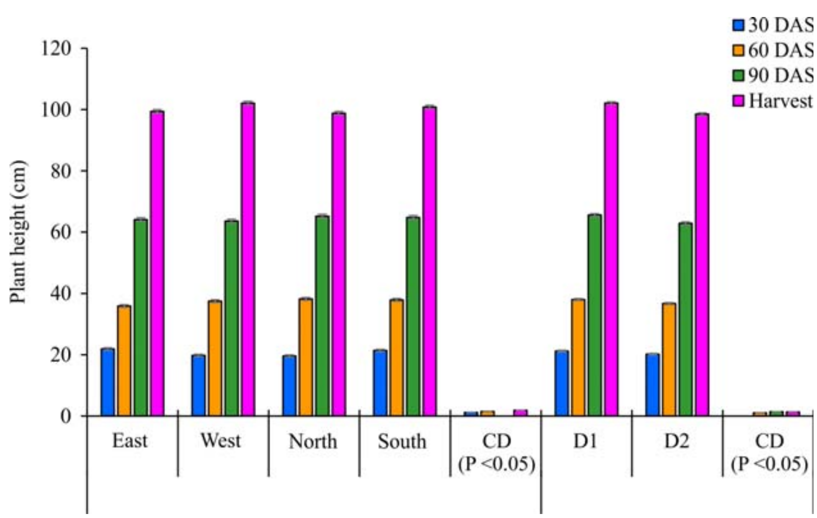

Fig. 1. Effect of distance and direction of *Melia* tree on plant height at different stages in wheat. Vertical bars on the column indicate standard error (n= 3)

height (102.1 cm) was recorded from the West direction which was statistically at par with the height recorded from South direction. However, minimum plant height (98.8 cm) was recorded from North direction and it was at par with East direction. The distance from the tree bole had significant effect on height of wheat crop (Fig. 1). At all growth stage, significantly higher height was recorded nearer (1.0 m) to the tree base. No interaction effect of distance and direction was observed on the plant height of wheat crop.

Effect of directions on dry weight of wheat was found significant at all growth stages (Table 3). The dry matter accumulation in South direction was recorded significantly higher as compared to other directions. At harvest, highest dry matter accumulation (629.3 g m^{-2}) was recorded in South direction, which was 9.99, 10.40 and 7.26% higher over the East, West and South direction, respectively. The distance from tree base also had significant effect on dry matter accumulation in wheat crop at all the growth stages. The dry matter accumulation at 2.0 m distance from tree basin was 3.59, 6.03, 4.59 and 6.24% higher over the dry matter accumulation at 1.0 m distance at 30, 60, 90 DAS and at harvest, respectively. The interaction effect of distance and direction was observed non-significant on the dry matter accumulation. Orientation of trees in agroforestry can lead to change in microclimate due to difference in light interception, evaporation and transpiration (Donat *et al*., 2023). The potential losses in biomass accumulation nearer to tree due to more competition of resources has also been reported by Upadhyaya *et al*. (2021) in teak+barley agroforestry system.

Chlorophyll content

Chlorophyll content was found comparatively higher in wheat plants of West and North direction as compared to East and South direction at 30 and 60 DAS (Fig. 2). However, no significant variation was observed among all the directions at 90 DAS. The distance effect was recorded significant higher at 1.0 m distance compared to 2.0 m distance from

Table 3. Effect of individual factor (distance and direction) of *Melia* tree and their interaction on dry weight (g m^{-2}) of wheat

Treatment	30 DAS	60 DAS	90 DAS	At Harvest
East (E)	28.4	127.0	299.4	572.1
West (W)	28.4	127.9	296.1	570.0
North (N)	29.8	128.9	301.6	586.7
South (S)	32.2	134.6	316.4	629.3
SEm (±)	0.16	1.25	2.61	2.07
$LSD_{0.05}$	0.50	3.82	8.01	6.33
D1	27.8	124.3	291.4	558.6
D2	28.8	131.8	304.8	593.5
SEm (±)	0.12	0.88	1.85	1.46
$LSD_{0.05}$	0.36	2.70	5.66	4.48
ED1	27.50	123.1	297.8	581.7
ED2	28.60	134.1	310.6	607.2
WD1	28.20	122.0	288.7	530.7
WD2	29.10	128.7	300.7	568.7
ND1	25.60	117.1	271.2	505.7
ND2	26.60	123.6	287.5	540.0
SD1	30.00	135.0	308.0	616.5
SD2	31.00	141.0	320.4	658.2
SEm (±)	0.23	1.76	3.70	2.92
$LSD_{0.05}$	NS	NS	NS	NS

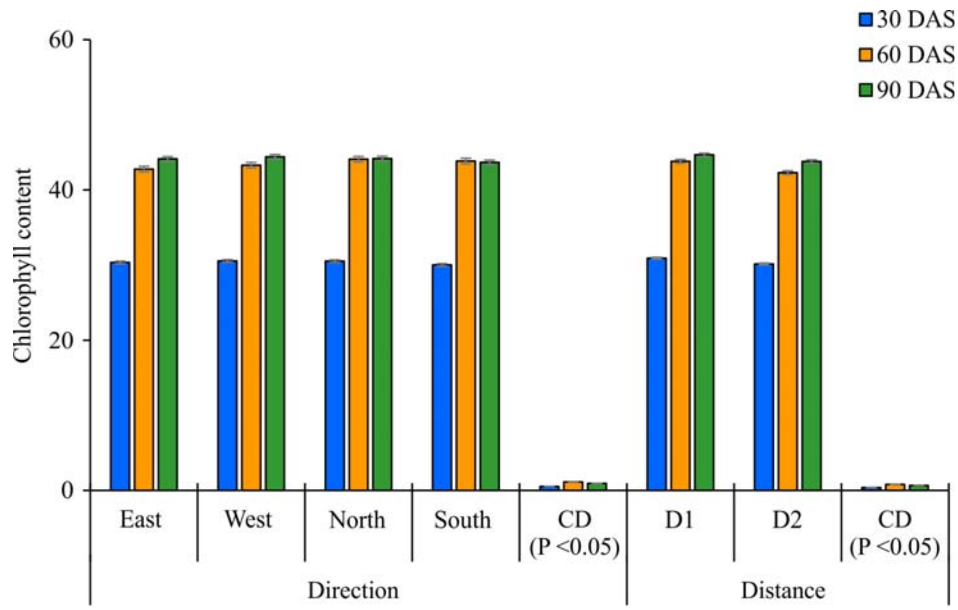

Fig. 2. Effect of distance and direction of *Melia* tree on chlorophyll content (SPAD Value) at different stages in wheat. Vertical bars on the column indicate standard error (n= 3)

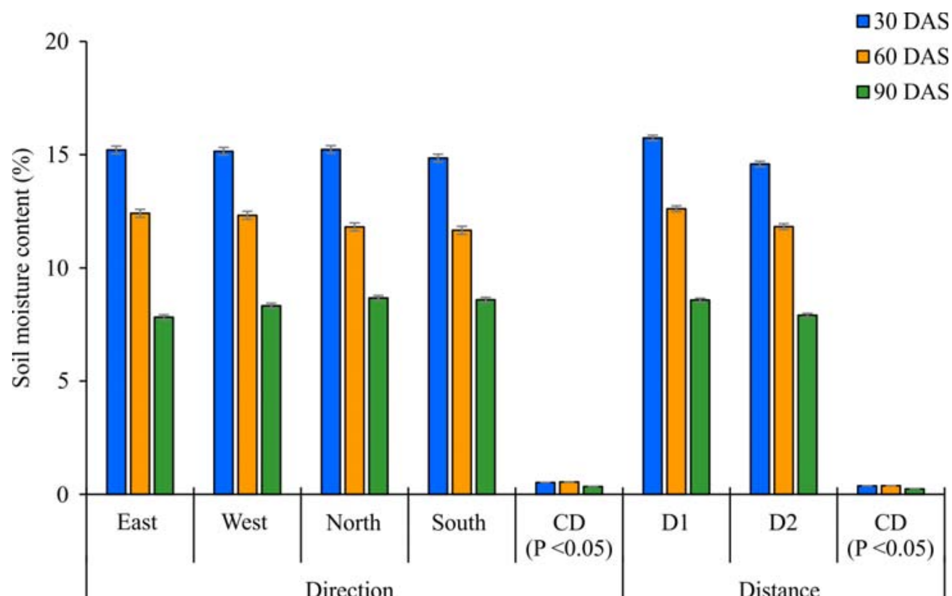

Fig. 3. Effect of distance and direction of *Melia* tree on soil moisture content in wheat. Vertical bars on the column indicate standard error (n= 3)

tree base. Leaves in shade are more efficient in capturing light due to higher chlorophyll content (Poorter *et al*., 2000). Increased chlorophyll content in shade has also been reported by Corzo-Bacallao *et al*. (2024) in coffee-based agroforestry system.

Soil moisture

The soil moisture content in crop root zone varied from 14.85 to 15.23% at 30 DAS, 11.66 to 12.41% at 60 DAS and 7.82 to 8.67% at 90 DAS in all the directions from the *Melia* tree (Fig. 3). However, no clear trend of soil moisture has been observed with respect to direction from tree. But, soil moisture content nearer to tree base (1.0 distance) was found significantly higher as compared to 2.0 m distance at all the growth stages of wheat crop. The two-way interaction between direction and distance did not show any significant effect on soil moisture content.

The variation in the soil moisture content at different distance from the tree trunk in all the directions has also been reported by (Godefroid and Koedam, 2010). However, variation in soil moisture content depend upon many factors of the ecosystem and it could not be generalized that presence of tree increase or decrease the soil moisture content (Gea-Izquierdo *et al*., 2009). For example, Martin-Guay *et al*. (2022) reported lower soil moisture content beneath the tree canopy as compared to open crop canopy.

Grain yield

Effect of directions and distances on yield of wheat was found significant (Table 4). Maximum grain yield (157.5 g m^{-2}) was recorded from East direction, followed by South direction (155.6 g m^{-2}). However, the grain yield recorded from these two directions were statistically at par with each other. The minimum grain yield was recorded from North direction (133.7 g m^{-2}). Distance from *Melia* tree base also showed significant effect on grain yield. The grain yield of wheat at 2.0 m distance was observed 10.92% higher than at 1.0 m distance (141.0 g m^{-2}). Yield of the understory crop in agroforestry system is affected by various factors such as soil moisture content, nutrient availability and intercepted light (Gao *et al*., 2013; Qiao *et al*., 2019; Upadhyaya *et al*., 2021). Chemura *et al*. (2021) reported the projected loss of 11% maize grain yield in 20% shade. Kumar *et al*. (2020) reported the higher crop yield in South-West direction compared to other directions due to variation in photosynthetic active radiation (PAR). Presence of shade, nutrient and water competition nearer to tree in alley cropping resulted in loss of 55% maize yield and 75% oilseed rape yield (Swieter *et al*., 2019) and corroborates to our findings.

Table 4. Effect of individual factor (distance and direction) of *Melia* tree and their interaction on grain yield (g m^{-2}) of wheat

Treatment	Grain yield (g m^{-2})
East (E)	157.5
West (W)	147.9
North (N)	133.7
South (S)	155.6
SEm (±)	1.32
$LSD_{0.05}$	4.03
D1	141.0
D2	156.4
SEm (±)	0.93
$LSD_{0.05}$	2.85
ED1	147.8
ED2	167.2
WD1	140.6
WD2	155.1
ND1	128.2
ND2	139.2
SD1	147.3
SD2	163.9
SEm (±)	1.86
$LSD_{0.05}$	NS

Conclusion

Light intensity, crop growth, grain yield and soil moisture varied in different direction and distance from the *Melia* tree. On the basis of results obtained from the present study, it was concluded that highest grain yield of wheat was recorded in East direction followed by South direction and significantly higher grain yield of wheat was recorded at 2 m distance from the tree base. However, tree-crop interactions depends upon many associated factors *viz*., tree spacing, moisture and nutrient availability in soil, management practices etc. The findings revealed that in the initial years, potential crops like wheat can successfully be grown under *Melia dubia*-based agroforestry system.

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