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Optimizing Pulse Cultivation: Impact of Malabar Neem (*Melia dubia* Cav.) Spacings on Growth and Yield of Lentil (*Lens culinaris* Medik.) Vis-a-Vis Soil Health in Semi-arid Conditions of Bundelkhand

Pradyumna Prataprao Deshmukh[1], Prabhat Tiwari[1], Manmohan J. Dobriyal[1], Ram Prakash Yadav[1], A.K. Handa[2], Varsha Shekhawat[1], Anuvarna K.[3], Mamta[1], Subhaprada Behera[4]

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ABSTRACT

Background: Lentil (*Lens culinaris*) is a major rainfed crop cultivated in Bundelkhand region and Malabar Neem (*Melia dubia*), a fast-growing tree species of significant economic and ecological importance. This study underscores the ecological benefits of optimized tree spacing with lentil varieties in agroforestry systems for Bundelkhand region.

Methods: The present study entitled was conducted during the year 2023-2024 employed a split plot design with four levels of tree spacings under main plot and two levels of lentil (*Lens culinaris*) varieties under sub-plot with three replications. Growth and yield analysis of lentil varieties was estimated along with effect of tree spacing on soil properties.

Result: The results revealing that from main plot, the sole cropping (G_0) and IPL 316 lentil variety (V_1) from sub-plot consistently outperformed intercropped treatments as it exhibited highest plant growth parameters, shorter number of days to 50% flowering and maturity along with higher yield attributes compared to the intercropped treatments. Yield decreased with increasing tree density, with the lowest values under the agroforestry system spaced at 5 m × 3 m (G_3) spacing. However, intercropping improved soil health, with the highest soil physico-chemical properties and microbial activity recorded in the agroforestry system spaced at 5 m × 3 m (G_3) spacing. Despite lower yields, intercropping promoted long-term soil sustainability. Overall, IPL 316 (V_1) was the best-performing variety and agroforestry with optimized tree spacing improved soil fertility in semi-arid regions.

Key words: Agroforestry system, *Lens culinaris*, *Melia dubia*, Sustainability, Tree spacing.

INTRODUCTION

Agroforestry is a system of managing natural resources that is based on ecology and involves integrating trees into farms and agricultural landscapes. This system aims to diversify and sustain production, leading to greater social, economic and environmental benefits for land users (Alao and Shuaibu, 2013). Agroforestry can support or improve the distribution of ecosystem services such as soil health and biodiversity, especially in response to a changing climate, ensuring that societal and economic demands continue to be satisfied (Handa *et al*., 2016). Presently, the total extent of agroforestry in India is about 28.42 million hectares, constituting 8.65% of the country's total geographical area (Arunachalam *et al*., 2022). Agroforestry has the potential to address multiple challenges in agricultural systems, including sustainable biological production, uncontrolled deforestation, soil fertility loss, drought occurrence and the escalating use of hazardous pesticides (Partel *et al*., 2024).

The Bundelkhand region in central India is situated in the semi-arid tropical zone. Due to the region's susceptibility to climate change and lack of resources, agricultural output is poor and the risks associated with production are consequently higher (Sharma, 2023). Promoting the cultivation of industrially useful trees on agricultural land in the Bundelkhand region is crucial for creating livelihood

[1]Department of Silviculture and Agroforestry, Rani Lakshmi Bai Central Agricultural University, Jhansi-284 003, Uttar Pradesh, India. [2]ICAR-Central Agroforestry Research Institute, Jhansi-284 003, Uttar Pradesh, India. [3]Department of Forest Product and Utilization, Rani Lakshmi Bai Central Agricultural University, Jhansi-284 003, Uttar Pradesh, India. [4]ICFRE-Bamboo and Rattan Centre, Aizawl-796 007, Mizoram, India.

Corresponding Author: Pradyumna Prataprao Deshmukh, Department of Silviculture and Agroforestry, Rani Lakshmi Bai Central Agricultural University, Jhansi-284 003, Uttar Pradesh, India. Email: deshmukhpradyumna4@gmail.com

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options for the local community (Chavan *et al*., 2016). Using rapidly growing, high-grade trees enables early harvesting and improves yield in agroforestry systems. Multipurpose trees (MPTs) are becoming more important in semi-arid regions of India as a means to support production and enhance income within the current system (Malik *et al*., 2013). *Melia dubia* can thrive as a tree in semi-arid parts of Northern India. *Melia dubia* is predominantly found in deciduous forests situated at elevations ranging from 600 to 1,800 meters. *Melia dubia* is found in the Indo-Malaysia region, as well as in Australia and the Western Ghats of India (Pratap and Pant, 2020). *Melia dubia*, with its diverse applications such as pulpwood, timber, plywood, fuel wood, agricultural implements, packing cases pencils and furniture, is a promising and ideal species for agroforestry and farm forestry plantation systems (Chauhan and Chauhan, 2011).

Melia dubia, a deciduous tree, undergoes dormancy in the winter season and this characteristic makes it as a suitable agroforestry tree species. It is a short rotation species with great utility as a raw material for pulp wood, plywood industry and high-quality timber for multiple uses (Thakur *et al*., 2023). The selection of crops for intercropping is crucial for effectively utilizing the space in agroforestry systems. Lentil (*Lens culinaris* Medik.) an important low water requiring winter legume crop, recognized for their flat, lens-shaped seeds. Lentil is mostly cultivated as a rainfed crop and need cold temperatures during their growth period and warmer temperatures for maturation (Kumar *et al*., 2013). Lentils are primarily grown in Uttar Pradesh, Madhya Pradesh, West Bengal, Chhattisgarh, Bihar and Jharkhand. The Bundelkhand region in Uttar Pradesh and Madhya Pradesh is particularly notable for its production, contributing about 25% of the nation's total production (Malik *et al*., 2022). Keeping in view the potential of *Melia dubia* as a commercially important fast-growing agroforestry tree species and suitability of lentil crop for the arid and semi-arid areas of Bundelkhand, the present study was planned with the objectives *viz*: evaluating the growth and yield performance of lentil (*Lens culinaris*) varieties under the different spacings of *Melia dubia* and to evaluate how the tree spacings influences the soil properties.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at field number H-12 at the plantation of *Melia dubia* at Forestry Research Farm, Bhojla under the Rani Lakshmi Bai Central Agricultural University, Jhansi (U.P.) (Fig 1). It is located in Uttar Pradesh's Agro-climatic Zone (6) and India's Agro Climatic Zone-VIII (Central Plateau and Hills Region Zone). The experimental site is located at an altitude of 284 meters above sea level (between 25.517457°N latitude and 78.561147°E longitude). The experimental field was fertile and had uniform topography and soil properties. The Bundelkhand region has a subtropical climate with extremely hot summers, cold winters and semi-arid conditions.

Experimental details

The research employed a split-plot design using *Melia dubia* arranged at 5 m × 5 m (G_1), 5 m × 4 m (G_2) and 5 m × 3 m (G_3) as main plots. The three spacings of *Melia dubia* were evaluated against sole cropping (G_0). During the experimental period, two lentil varieties were in the subplots, namely V_1 (IPL 316) and V_2 (L 4727) and replicated three times. These two varieties are low water requiring varieties and recommended for growing in the Bundelkhand



Fig 1: Experimental view of the Lentil-Melia based agroforestry system at RLBCAU, Jhansi.

region. IPL 316, developed by ICAR-IIPR, Kanpur in 2013, matures in 110-115 days and is resistant to wilt and rust. Another variety, L 4727, was developed by ICAR-IARI, New Delhi in 2018 and matures in 92-128 days. L 4727 is moderately resistant to wilt. The sowing of lentil was done at 30 cm × 10 cm with seed rate of 40 kg ha^{-1}. The recommended doses of nitrogen, phosphorus, potassium and sulphur were applied at 20 kg ha^{-1}, 40 kg ha^{-1}, 20 kg ha^{-1} and 20 kg ha^{-1} respectively. Weeding was done at 30, 60 and 90 days after sowing and intercultural operations were done as required. The lentil crop was harvested in March month.

Crop growth and yield analysis

The different growth traits, namely plant height, number of primary branches per, number of root nodules at 90 days after sowing, dry matter accumulation, days to 50% flowering and days to physiological maturity were recorded during growing season. However, the yield traits, namely number of pods per plant, number of seeds per pod, grain yield, straw yield, biological yield, harvest index and grain to straw ratio were recorded after harvesting of the crop during March 2024.

Soil analysis

The soil samples were analyzed at a depth of 0-15 cm for their physical, chemical and biological properties. Bulk density was determined using the core sampler technique (Singh, 1980), while the Pycnometer Method was utilized to assess soil particle density. The soil pH was determined by using 1:2 soil-water suspensions and monitored using a pH meter and electrical conductivity meters (Jackson, 1973). Organic carbon was measured with the chromic acid titration technique (Walkley and Black, 1934). The nitrogen concentration in the soil samples was evaluated utilizing the alkaline potassium permanganate method (Subbiah and Asija, 1956). Available phosphorus (P) was extracted utilizing Olsen's method (Olsen *et al*., 1954). The quantification of available potassium was conducted using the neutral normal ammonium acetate method (Jackson, 1973). The presence of sulphur in soil is evaluated by the turbidimetric method (Williams and Steinberg, 1969). The microbiological parameters were evaluated, specifically the total *via*ble microbial count (bacteria and fungus) by the serial dilution method (Subba Rao, 1999) and microbial biomass carbon using the soil fumigation-extraction method (Vance *et al*., 1987). Dehydrogenase (Tabatabai, 1994) and phosphatase activity (Tabatabai and Bermner, 1969) were also utilized in soil analysis.

Statistical analysis

Conclusions were drawn by tabulating and statistically evaluating the growth parameters and yield attributes. The treatment differences were evaluated using the 'F' test grounded on the null hypothesis. At the 5% significance level, where the 'F' test yielded significant results, the crucial differences were computed (Gomez and Gomez, 1984). The Pearson correlation plot was generated using the 'metan' function in R-studio.

RESULTS AND DISCUSSION

Growth attributes

The different growth attributes of lentil crop were significantly (p<0.05) influenced by tree spacings and varieties were recorded and are presented in Table 1. It was recorded that, the significant highest growth attributes of lentil varieties were observed in sole cropping *viz*. plant height, number of primary branches per plant, number of root nodules per plant at 90 DAS and dry matter accumulation, *i.e*., 38.93 cm, 5.31 $plant^{-1}$, 1.23 $plant^{-1}$ and 9.48 g $plant^{-1}$ respectively, which was followed by the agroforestry system spaced at 5 m × 5 m, while the lowest was found under the agroforestry system spaced at 5 m × 3 m (G_3). The significantly highest days to 50% flowering was taken by 5 m × 3 m (G_3) (91.43 days) which was at par with 5 m × 4 m (G_2) (90.5 days) and 5 m × 5 m (G1) (87.55 days). The significantly highest days to physiological maturity were taken by

Table 1: Impact of *Melia dubia* tree spacing on growth attributes of lentil crop.

	Plant height (cm)	No. of primary branches ($plant^{-1}$)	No. of root nodules at 90 DAS ($plant^{-1}$)	Dry matter accumulation (g $plant^{-1}$)	Days to 50% flowering	Days to physiological maturity
Tree spacings						
G_0	38.93	5.31	1.23	9.48	77.43	125.1
G_1	36.38	5.13	1.13	8.76	87.55	129.4
G_2	34.87	4.87	1.07	8.48	90.5	131.5
G_3	33.11	4.66	1.03	8.34	91.43	135.02
SEm±	0.4	0.04	0.02	0.06	1.8	0.47
$CD_{0.05}$	1.41	0.12	0.06	0.2	6.24	1.65
Lentil varieties						
V_1	36.42	5.08	1.13	8.87	85.13	128.35
V_2	35.23	4.92	1.1	8.67	88.32	132.18
SEm±	0.18	0.04	0.01	0.06	0.95	1.01
$CD_{0.05}$	0.58	0.14	0.02	0.2	3.09	3.31

agroforestry system spaced at 5 m × 3 m (G_3) (135.02 days). Among the lentil varieties, it was recorded that, the significant highest growth attributes of lentil varieties were observed in IPL 316 (V_1) *viz*. plant height, number of primary branches per plant and number of root nodules per plant at 90 DAS, *i.e.*, 36.42 cm, 5.08 plant^{-1}, 1.13 plant^{-1} respectively. The dry matter accumulation was significantly highest in IPL 316 (V_1) (8.87 g plant^{-1}) which was statistically at par with L 4727 (V_2) (8.67 g plant^{-1}). The days to 50% flowering and days to physiological maturity of lentil varieties was observed significantly highest in L 4727 (V_2) *viz*. 88.32 days and 132.18 days. The differences in plant growth parameters between sole crops and intercrops can be attributed to factors such as increased sunlight, space and reduced competition for nutrients, which foster a more conducive environment for crop growth. Katariya *et al*. (2023) observed that sole cropping yields higher growth parameters compared to agroforestry systems. The decline in root nodules as crops mature can be linked to the senescence phase, which involves nutrient transfer (Pandey *et al*., 2023), aligning with findings by Singh and Jhariya (2014) regarding soybean in poplar-based systems. Sole crops generally produce more dry matter than those in agroforestry systems, attributed to the competition for resources, as trees with deeper roots absorb more nutrients and water (Keprate *et al*., 2024). Additionally, sole crops tend to reach flowering and physiological maturity earlier due to greater access to photosynthetically active radiation. Parasriya *et al*. (2022) also found that *Vigna radiata* in sole cropping matured faster than when intercropped with *Melia dubia*, reinforcing the advantages of sole cropping in terms of growth and development timelines.

Yield attributes

Significant variations were observed in the yield attributes of lentil varieties under different tree spacing and sole cropping (Table 2). The significantly highest number of pods plant^{-1} of lentil varieties was observed in sole cropping (G_0) (87.03), which was at par with agroforestry system spaced at 5 m × 5 m (G1) (83.2). The significantly

Table 2: Impact of *Melia dubia* tree spacing on yield attributes of lentil crop.

	No. of pods (plant^{-1})	No. of seeds (pod^{-1})	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	Grain to straw ratio
Tree spacings								
G_0	87.03	1.52	22.18	1022	1751	2773	36.86	0.58
G_1	83.2	1.5	22.15	957	1674	2631	36.36	0.57
G_2	76.89	1.49	22.12	920	1642	2563	35.91	0.56
G_3	72.12	1.49	22.08	890	1620	2510	35.46	0.54
SEm±	1.32	0.01	0.22	12.22	14.89	20.52	0.33	0.01
$CD_{0.05}$	4.58	NS	NS	42.31	51.55	71.04	NS	NS
Lentil varieties								
V_1	81.22	1.53	22.16	959	1687	2646	36.23	0.56
V_2	78.4	1.47	22.11	936	1657	2593	36.07	0.56
SEm±	0.74	0.01	0.15	5.83	8.86	11.71	0.17	0.01
$CD_{0.05}$	2.39	0.04	NS	19.01	28.91	38.2	NS	NS

Table 3: Impact of *Melia dubia* tree spacing on soil physico-chemical properties.

	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Soil pH	EC (dS m^{-1})	Organic carbon (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available S (mm kg^{-1})
Tree spacings									
G_0	1.33	2.53	7.09	0.16	0.4	176.8	8.85	168.87	14.24
G_1	1.34	2.57	6.96	0.19	0.45	182.52	9.22	176.4	15.22
G_2	1.34	2.59	6.91	0.2	0.48	185.59	9.34	181.14	15.43
G_3	1.37	2.61	6.91	0.21	0.5	189.26	9.31	184.78	15.51
SEm±	0.01	0.02	0.07	0.01	0.01	2.2	0.14	2.01	0.13
$CD_{0.05}$	NS	NS	NS	NS	0.02	7.62	0.48	6.93	0.46
Lentil varieties									
V_1	1.35	2.58	6.97	0.19	0.45	183.35	9.18	177.57	15.1
V_2	1.35	2.58	6.97	0.2	0.46	183.74	9.19	178.04	15.11
SEm±	0.01	0.01	0.05	0.01	0.01	2.11	0.15	2.7	0.22
$CD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

highest grain yield, straw yield and biological yield of lentil varieties was observed in sole cropping (G_0) *viz*. 1022 kg ha^{-1}, 1751 kg ha^{-1} and 2773 kg ha^{-1} respectively which was followed by agroforestry system spaced at 5 m × 5 m (G_1). There was no significant effect of tree spacing on seeds per pod, test weight, harvest index and grain to straw ratio of lentil varieties. Amongst the lentil varieties, it was recorded that, the significant highest yield attributes of lentil varieties were observed in IPL 316 (V_1) *viz*. number of pods plant^{-1}, number of seeds pod^{-1}, grain yield, straw yield and biological yield of lentil varieties, *i.e*., 81.22, 1.53 plant^{-1}, 959 kg ha^{-1}, 1687 kg ha^{-1} and 2646 kg ha^{-1}. The impact of intercropping on crop yield characteristics has been extensively studied, revealing that intercrops often perform poorly compared to sole crops. Ajaykumar *et al*. (2021) noted a reduced number of pods per plant in *Vigna mungo* when intercropped with *Melia dubia* compared to sole cropping. Similarly, Thakur and Verma (2014) found a decrease in pod count for lentils grown under peach and mulberry agroforestry systems compared to monocropping. Bhusara *et al*. (2018) found that the Meha variety of green gram yielded more in sole cropping than when intercropped with *Melia composita*. Kumar and Nandal (2004) similarly reported lower yields for lentils intercropped with *Eucalyptus tereticornis*. Hemalatha *et al*. (2025) also found reduction in yield of cluster bean cultivars under *Melia dubia* based agroforestry system as compared to open conditions.

Physico-chemical and microbial properties of the soil

Table 3 indicates that tree spacing has resulted in significant improvements in soil physico-chemical properties, with no change in bulk density, particle density, soil pH and EC when evaluated post-experimental time. Organic carbon was significantly highest in agroforestry system spaced at 5 m × 3 m (G_3) (0.5%), whereas available nitrogen (189.26 kg ha^{-1}), available potassium (184.78 kg ha^{-1}) and available sulphur (15.51 mm kg^{-1}) showed significantly higher values under the agroforestry system spaced at 5 m × 3 m (G_3) tree spacing compared to sole cropping (G_0). Notably, agroforestry system spaced at 5 m × 3 m (G_3) tree spacing was statistically at par with agroforestry system spaced at 5 m × 4 m (G_2) and 5 m × 5 m (G_1) for available nitrogen and available sulphur whereas it was statistically at par with agroforestry system spaced at 5 m × 4 m (G_2) for available potassium. Available phosphorus was significantly highest in agroforestry system spaced at 5 m × 4 m (G_2) which was at par with agroforestry system spaced at 5 m × 5 m (G_1) and 5 m × 3 m (G_2). The dehydrogenase, bacterial count, fungal count, soil microbial biomass carbon, acid phosphatase and alkaline phosphatase was significantly higher in agroforestry system spaced at 5 m × 3 m (G_3) (Table 4) *viz*. 12.3 µg TPF g^{-1} day^{-1}, 48.6 × 10^{6} g^{-1} soil, 69.6 × 10^{4} g^{-1} soil, 898 µg g^{-1}, 48.27 µg pNP g^{-1} hr^{-1} and 34.59 µg pNP g^{-1} hr^{-1} respectively. Soil microbial biomass carbon and acid phosphatase was significantly higher in agroforestry system spaced at 5 m × 3 m (G_3) which was statistically at par with agroforestry system spaced at 5 m × 4 m (G_2). In agroforestry systems, non-nitrogen-fixing trees can improve soil physical, chemical and biological characteristics by introducing significant amounts of organic matter and releasing and recycling nutrients (Bhattacharyya *et al*., 2024). Similar findings were given by Uthappa *et al*. (2015); Narender *et al*. (2021); Subbulakshmi *et al*. (2021) and Sumit *et al*. (2024) that soil under agroforestry has higher available nitrogen, phosphorus and potassium in agroforestry than in sole cropping. Singh *et al*. (2024) revealed that the agroforestry system utilizing *Melia dubia* exhibited the highest populations of total *via*ble bacteria and fungi. The current study's observations (Fig 2) are corroborated by Radhakrishnan and Varadharajan (2016) who identified a positive correlation that soil nutrients altered the microbial community under agroforestry systems. Berry *et al*. (2023) reported positive correlation between different soil properties in *Cajanus cajan* based silvi-horti-agri system.

Table 4: Impact of *Melia dubia* tree spacing on soil biological properties.

	Dehydrogenase (µg TPF g^{-1} day^{-1})	Bacterial count (×10^{6} g^{-1} soil)	Fungal count (×10^{4} g^{-1} soil)	SMBC (µg g^{-1})	Acid phosphatase (µg pNP g^{-1} hr^{-1})	Alkaline phosphatase (µg pNP g^{-1} hr^{-1})
Tree spacings						
G_0	6.67	37	40.5	722	36.79	24.2
G_1	9.95	43.5	60	861.7	45.59	29.62
G_2	11.11	46.5	66.5	883.6	47.39	32.38
G_3	12.3	48.6	69.6	898	48.27	34.59
SEm±	0.06	0.38	0.74	6.72	0.36	0.36
$CD_{0.05}$	0.23	1.31	2.54	23.26	1.26	1.25
Lentil varieties						
V_1	9.97	44.25	59.5	841.85	44.79	30.27
V_2	10.04	43.5	58.75	840.8	44.23	30.12
SEm±	0.05	0.38	0.48	5.6	0.24	0.31
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

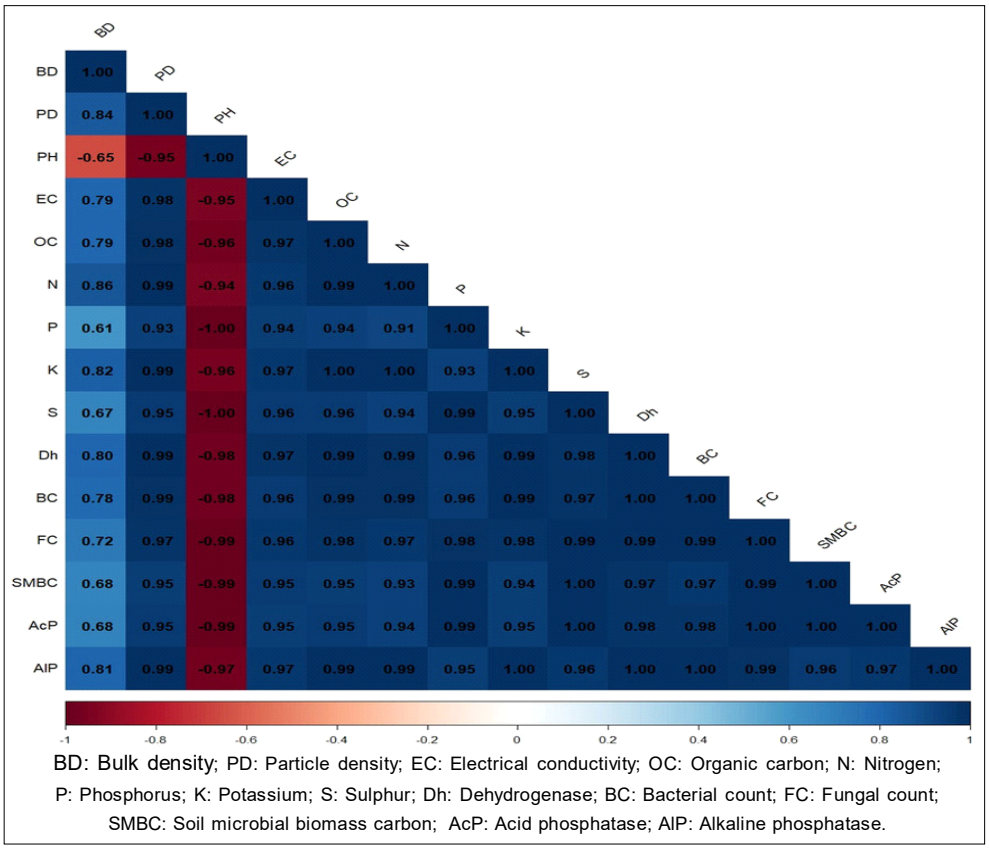


Fig 2: Correlation between soil physicochemical properties and soil microbial population as influenced by *Melia dubia* tree spacings and lentil varieties.

Correlation

Karl Pearson's correlation coefficient was calculated to analyze the correlations between soil physico-chemical and microbial parameters, as depicted in Fig 2. Among the various elements examined, it is evident that several parameters demonstrate relationships with one another. PD, EC, OC, N, P, K, S, Dh, BC, FC, SMBC, AcP and AlP exhibit exceptionally strong correlations with one another (0.95-1.00). This signifies that if a single parameter increases, the others often rise proportionally, implying dependency in nutrient cycling and soil health factors. The pH exhibits a significant negative correlation with the majority of other parameters, particularly P (-1.00), S (-1.00) and SMBC (-0.99). BD exhibits moderate positive correlations with several parameters, including PD at 0.84 and N at 0.86, while demonstrating a negative association with pH at -0.65. This suggests that BD influences nutrient dynamics, but to a lesser extent than pH or EC.

CONCLUSION

The present study highlights the impact of *Melia dubia* tree spacing on lentil (*Lens culinaris*) growth, yield and soil health in the semi-arid conditions of Bundelkhand. The findings reveal that sole cropping (G_0) consistently outperformed intercropped treatments in terms of plant growth parameters, early flowering and higher yield attributes due to minimal competition for light, nutrients and space. However, intercropping under a 5 m × 3 m (G_3) spacing showed notable improvements in soil health indicators, including enhanced organic carbon, nutrient availability and microbial activity, demonstrating the potential of *Melia dubia*-based agroforestry systems for sustainable soil management. Among the lentil varieties, IPL 316 (V_1) exhibited superior growth and yield performance compared to L 4727 (V_2), making it a more profitable choice for agroforestry-based farming in resource-constrained regions. Overall, this study underscores the ecological and economic benefits of integrating *Melia dubia* with lentil cultivation in an optimized agroforestry system. By balancing crop yield with soil sustainability, such systems offer a *via*ble approach to enhancing productivity, improving soil fertility and increasing financial returns for farmers in semi-arid regions.

Conflict of interest

The authors hereby declare that there are no conflicts of interest, whether financial, personal, or professional, that could have influenced the findings or interpretation of the results presented in the manuscript.

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