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Tree integration in conservation agriculture: A case study of teak (*Tectona grandis*) + bael (*Aegle marmelos*) based agroforestry in the Bundelkhand region

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ABSTRACT

The present study was carried out during the winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Central Agroforestry Research Institute, Jhansi, Uttar Pradesh to study the impact of conservation agriculture practices within a teak (*Tectona grandis* L.) + bael (*Aegle marmelos* L.)-based agroforestry system on growth rate and yield parameters of tree and crop component, as well as on soil properties. It examined the effect of tillage methods and residue retention on the growth and yield of chickpea (*Cicer arietinum* L.) and linseed (*Linum usitatissimum* L.) as well as soil properties. The experiment was laid out in a randomized block design (RBD), with three replications having eight treatments of comprising combinations, viz. Tillage methods (conventional and minimum); Cropping systems (sorghum-chickpea and maize-linseed); and Residue management practices (residue retention and no retention). Results indicated that residue retention under conventional tillage significantly enhanced plant height and dry matter accumulation in both linseed and chickpea. Crop yields were comparable under conventional and minimum tillage, although residue retention significantly boosted the yields of both crops. Conservation agricultural practices contributed to higher productivity in the teak + bael-based agroforestry system. Residue retention improved soil organic carbon content by 24–39% compared to no residue retention. Additionally, nutrient availability (N, P, K, S, Zn, Fe, Mn, and Cu) was enhanced through minimum tillage combined with residue retention.

Keywords: Agro-ecosystem, Agroforestry, Conventional tillage, Minimum tillage, Climate change, Residue management

The degradation of agro-ecosystems and declining sustainability pose significant obstacles to agricultural progress in India (Bhattacharyya *et al.* 2015). These challenges, compounded by reduced financial returns and the high risks associated with farming, have made agriculture less attractive to many farmers (Ram *et al.* 2016). Rainfed agriculture practiced in more than half of the net cultivated area produces around 40% of the total (Chary *et al.* 2022). The Bundelkhand region, located in Central India, experiences a semi-arid tropical climate where crop productivity remains low due to climatic vulnerability and resource scarcity (Dev *et al.* 2020, Choudhary *et al.* 2022), hence farm diversification is key recommended strategies to accentuate livelihood security of Bundelkhand's farmers (Kumar *et al.* 2022, Sharma *et al.* 2021)

Conservation agriculture (CA), an environmentally conscious farming method aimed at boosting productivity while safeguarding natural resources. The pivotal role of CA in boosting resilience against climate vulnerabilities and enhancing soil, water, and ecosystem quality is well known (Sasode *et al.* 2020, Teng *et al.* 2024). This approach promotes better water infiltration and retention, vital during periods of drought or heavy rainfall. Implementing CA can lead to reduced input costs for farmers due to lower fertilizer and water requirements over time. This economic efficiency is complemented by the potential for increased yields and improved soil conditions, and thus making it a viable option for overall agricultural development in sustainable manner (Alam *et al.* 2018, Salahin *et al.* 2021).

Agroforestry systems, which integrate various components like trees, crops, forages, and livestock, offer numerous advantages, including stable incomes, enhanced environmental conservation, and improved agricultural productivity (Dhyani *et al.* 2016, Jinger *et al.* 2024).

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Integration of CA with agroforestry can significantly improve soil quality through enhancing chemical, biological, and physical properties. CA and agroforestry together may offer long-term solutions (Teng *et al.* 2024) for resilience to climate vulnerabilities (Schroth *et al.* 2004). In this backdrop, to the study assessed the impact of conservation agriculture practices within a teak (*Tectona grandis* L.) + bael (*Aegle marmelos* L.)-based agroforestry system on growth rate and yield parameters of tree and crop component, as well as on soil properties.

MATERIALS AND METHODS

Study site: The present study was carried out during the winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Central Agroforestry Research Institute, Jhansi (25.50 º N, 78.54 º E), Uttar Pradesh .

Experimental design: The study was carried out within a seven-year-old teak + bael agroforestry system. Eight treatments comprising combinations of tillage, cropping system and residue application, viz. T_1, Conventional tillage (without crop residue retention)- chickpea; T_2, Conventional Tillage (without crop residue retention)-linseed; T_3, Minimum tillage (without crop residue retention)-chickpea; T_4, Minimum tillage (without crop residue retention)-linseed; T_5, Minimum tillage (with crop residue retention)-chickpea; T_6, Minimum tillage (with crop residue retention)-linseed; T_7, Conventional tillage (with crop residue retention)-chickpea; and T_8, Conventional tillage (with crop residue retention)-linseed were used for the experiment. The experiment was laid out in a randomized block design (RBD), with three replications. Teak and bael trees were planted in 2014, planted in alternating rows with a spacing of 9 m between rows and 4 m between plants within each row.

Tree details: Tree growth data were recorded at harvesting of *rabi* crops in 2022–23. The average height, DBH, and crown spread of bael plants were 5.15 m, 15.60 cm, and 4.73 m, respectively. The corresponding values for the teak were 9.73 m, 15.74 cm, and 6.11 m, respectively. The annual leaf litter addition from bael and teak was estimated (average of 2021–22 and 2022–23) to be 0.175 t/ha and 0.409 t/ha, respectively.

Crop management: This study focuses on the observation on linseed (maize-linseed) and chickpea (sorghum-chickpea cropping system) crops. Residues of the previous crops, namely sorghum and maize, were retained @1.0 t/ha in the respective treatments. In the conventional tillage treatment, field preparation involved one deep ploughing, followed by two rounds of harrowing, planking, and seeding. Conversely, the minimum tillage treatment included a single light ploughing followed directly by the seeding operation. Following field preparation, a local variety of linseed (seed rate @30 kg/ha) and Jaki 9218 variety of chickpea (seed rate @80 kg/ha) were sown. Except for the specified treatments, the recommended package of practices was uniformly adopted for both crops to ensure proper growth and management.

Observations: Observations on the growth attributing characters of linseed and chickpea i.e. plant height (cm) were recorded on 10 randomly selected and tagged plants at 30, 60, and 90 days after sowing (DAS) and at harvest and average were taken. Dry matter accumulation (g/m^2) was recorded by sampling plants in a quadrant of 1 m^2 in such a way that the impact of tree shade was equally considered in all the treatments. Further, yield attributing characters of linseed (capsules in one plant, seeds in one capsule, length of pod, and test weight) and chickpea (length of pod, pods/plant, test weight) were recorded from 10 randomly selected plants from each replicated plot at harvest stage. For determining the yields of both the crops i.e. linseed and chickpea, the crops at maturity stage were harvested in a 2 m × 2 m quadrant area at three randomly selected locations in each treated plot, and yields (seed, stover and biological) and harvest index (%) were worked out.

The market price of linseed and chickpea was different, hence to compare the productivity of both the crops under different tillage and residue treatments, chickpea equivalent yield was worked out by converting the linseed yields into chickpea equivalent yield (CEY) as per following formula:

$$\text{Chickpea equivalent yield (kg/ha)} = \frac{\text{Yield of linseed (kg/ha)} \times \text{Market price of linseed (₹/kg)}}{\text{Market price of chickpea (₹/kg)}}$$

The prevailing market prices of chickpea (₹52.50/kg), linseed (₹58.00/kg) were used for calculating the chickpea equivalent yield for the study.

Soil analysis: Soil samples were collected, processed and analysed for soil organic carbon, macronutrients such as nitrogen phosphorus, potassium, sulphur and DTPA-extractable micronutrients (Fe, Zn, Mn, Cu) using standard analytical techniques.

Statistical analysis: The data relating to crop growth parameters, yield attributes, yield and soil nutrient availability of both seasons (2021–22 and 2022–23) were pooled and analysed using ANOVA. Following Gomez and Gomez (1984), F-test was conducted to determine the significant variations of the treatment combinations. Further, taking clue from Gopinath *et al.* (2020), the bar chart with grouping analysis were performed using the Grapes site. Additionally, a correlogram and principal component analysis (PCA biplot) were performed using RStudio (R Studio Team 2014).

RESULTS AND DISCUSSION

Growth parameters: At all growth stages of linseed, the maximum plant height was recorded in the T_8 treatment (conventional tillage with residue application), measuring 15.15 cm, 47.10 cm, 62.40 cm, and 66.26 cm at 30, 60, 90 DAS and at harvest, respectively followed by T_6 (minimum tillage with residue application). At the harvest stage, the maximum linseed plant height of 66.26 cm observed in T_8 was statistically comparable to the 65.40 cm recorded under T_6. Similar trend was noticed in chickpea. The T_7 treatment (conventional tillage with residue application) achieved the maximum plant height of 48.36 cm at harvest, followed closely by T_5 (minimum tillage with residue application). The two treatments were statistically comparable (Table 1). Applying residue significantly boosted the plant height of both linseed and chickpea, regardless of the tillage method employed (Table 1).

Similarly, dry matter accumulation in linseed at 30, 60, 90 DAS, and harvest stage was maximum with conventional tillage with residue application (T_8). At the harvest stage, the maximum dry matter was 409.8 g/m^2, however, it was at par with the dry matter recorded in T6 (394.0 g/m^2). Further, it is observed that among different treatments, lesser dry matter accumulation was observed in the treatments without residue applications. The lowest dry matter accumulation (330.6 g/m^2) was observed in minimum tillage without residue (T_4), however statistically it was at par with conventional tillage without residue (T_2). A similar trend was observed for chickpea (Table 1) and conventional tillage with residue application (T_7) resulted in higher (24.2, 136.3, 307.9, 517.6 g/m^2 at 30, 60, 90 DAS and at harvest, respectively) dry matter accumulation in chickpea over T_5 and T_1 treatments. Compared to tillage treatments, residue application had a greater impact on total dry matter accumulation. In the T_7 treatment, a dry matter yield of 517.6 g/m² was recorded, the highest among all treatments. This value was statistically comparable to that of the T_5 treatment. The lowest dry matter accumulation (467.2 g/m^2) was recorded in minimum tillage without residue application (T_3) which was statistically at par with conventional tillage without residue application (T_1). Higher growth parameters in linseed and chickpea with conventional tillage with residue application may be attributed to the impact of residue application on weeds, soil moisture conservation, and nutrient addition. Literature suggests that continuous residue retention reduces total weed density and dry matter. Specifically, plots with residue over three years accumulated 16.7% less dry matter compared to those without residue (Jat *et al.* 2019). Singh *et al.* (2022a) highlighted the similar findings in chickpea and Kakraliya *et al.* (2018) in paddy.

Yield attributes and crop yields: Conventional tillage with residue application significantly improved yield-attributing traits of linseed, such as the number of capsules/plant and the number of seeds/capsule, compared to minimum tillage and conventional tillage without residue application (Table 2). The highest number of capsules/plant (54.06) and seeds/capsule (6.83) were recorded in T_8 (conventional tillage with residue application). In contrast, the lowest values were observed in T_4 (minimum tillage without residue application), with 44.40 capsules/plant and 6.15 seeds/capsule. These values were statistically comparable to those recorded in T_2 (conventional tillage without residue application). However, tillage and residue application treatments had no significant effect on the test weight of linseed. The results revealed that the application of residue under conventional tillage (T_8) produced a significantly higher seed yield of linseed (890.2 kg/ha) compared to

Table 1 Effect of conservation agriculture practices on plant height and dry matter accumulation of linseed and chickpea in teak + bael-based agroforestry system (Pooled data of two years)

Treatments	Linseed								Chickpea							
	Plant height (cm)				Dry matter accumulation (g/m^2)				Plant height (cm)				Dry matter accumulation (g/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1, CT (-R)-Chickpea	-	-	-	-	-	-	-	-	11.14	24.42	38.99	45.36	22.2	125.2	277.8	479.2
T_2, CT (-R)-Linseed	12.85	44.10	57.39	60.60	22.52	224.1	336.4	356.0	-	-	-	-	-	-	-	-
T_3, MT(-R)-Chickpea	-	-	-	-	-	-	-	-	10.13	23.18	37.35	45.66	21.1	122.1	272.8	467.2
T_4, MT (-R)-Linseed	13.15	41.94	55.37	57.95	22.34	214.6	321.4	330.6	-	-	-	-	-	-	-	-
T_5, MT(+R)-Chickpea	-	-	-	-	-	-	-	-	11.37	25.55	40.33	48.70	23.6	135.2	306.9	493.8
T_6, MT(+R)-Linseed	14.00	46.25	61.31	65.40	25.68	243.3	383.1	394.0	-	-	-	-	-	-	-	-
T_7, CT(+R)-Chickpea	-	-	-	-	-	-	-	-	11.75	26.85	40.11	48.36	24.2	136.3	307.9	517.6
T_8, CT(+R)-Linseed	15.15	47.10	62.40	66.26	26.50	256.9	392.9	409.8	-	-	-	-	-	-	-	-
SEm±	0.28	0.90	1.18	1.25	0.49	4.8	7.3	7.6	0.30	0.40	0.64	0.77	0.5	1.8	5.0	6.9
LSD (P=0.05)	0.97	3.10	4.10	4.34	1.71	16.5	25.2	26.2	1.04	1.39	2.21	2.66	1.8	6.3	17.3	23.7

DAS, Days after sowing; CT, Conventional tillage; MT, Minimum tillage; +R, With crop residue; -R, Without crop residue.

other treatments, except T_6 (minimum tillage with residue application). The seed yield in T_8 was 20.28% higher than that recorded in T_4 (minimum tillage without residue application). A similar trend was observed for stover yield, with T_8 registering the highest stover yield (1449.1 kg/ha), which was statistically comparable to T_6. The harvest index of linseed ranged from 37.55–38.05%.

The application of crop residue had a positive effect on the yield-attributing traits and yield (seed and stover) of the chickpea crop (Table 2). The results indicated that conventional tillage with residue application (T_7) accentuated the number of pods per plant (38.16) in chickpea significantly, although this was statistically comparable to T_5 (36.87). Tillage and residue management treatments had no significant effect on the number of grains/pod or 1000-seed weight in chickpea. Compared to minimum tillage without residue (T_3), seed yield increased by 14.76% under minimum tillage with residue application (T_5) and by 19.90% under conventional tillage with residue application (T_7). Similarly, the highest stover yield (2858.2 kg/ha) was recorded under T_7, whereas the lowest (2482.9 kg/ha) was observed in T_3. The data also indicated that the highest harvest index (31.9%) was achieved with conventional tillage and residue application (T_7).

To compare the linseed and chickpea productivity with different tillage and residue retention treatments, chickpea equivalent yield (CEY) was calculated for the seed yield of linseed (Fig. 1). Amongst all the treatments, the highest chickpea equivalent yield (1340 kg/ha) was observed with T_7 treatment (conventional tillage with crop residue-Linseed) followed by T_5 treatment (minimum tillage

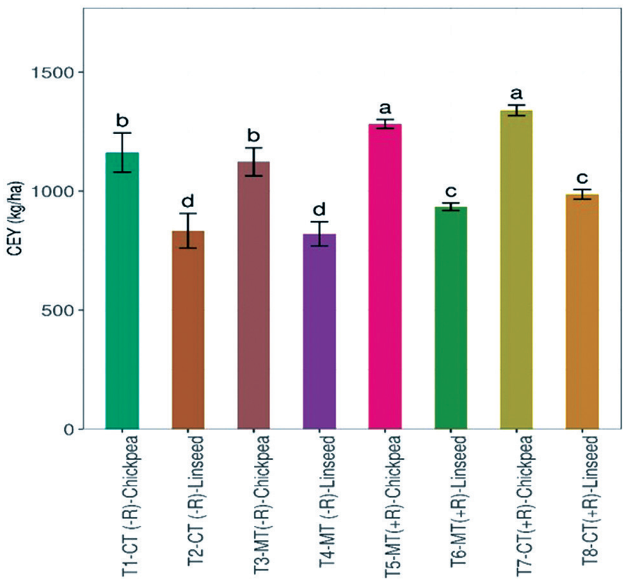

Fig. 1 Effect of tillage and residue treatment on chickpea equivalent yield (CEY) of chickpea and linseed crops under teak+bael-based conservation agroforestry system (Pooled data of two years). (Grouping is based on LSD test).
Treatments with same letters are not significantly different at 5% level). CT, Conventional tillage; MT, Minimum tillage; +R, With crop residue; -R, Without crop residue.

Table 2 Effect of conservation agriculture practices in yield attributes and yields of linseed and chickpea in teak + bael-based agroforestry system (Pooled data of two years)

Treatments	Linseed						Chickpea					
	No. of capsule/ plant	No. of seed/ capsule	Test weight(g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	No. of pod / plant	No. of seed /pod	1000-seed weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
T_1, CT (-R)-Chickpea	-	-	-	-	-	-	34.11	1.67	125.8	1162.8	2573.0	31.1
T_2, CT (-R)-Linseed	45.56	6.20	6.44	752.6	1247.3	37.62	-	-	-	-	-	-
T_3, MT(-R)-Chickpea	-	-	-	-	-	-	32.51	1.64	124.2	1123.8	2482.9	31.2
T_4, MT (-R)-Linseed	44.40	6.15	6.26	740.1	1230.5	37.55	-	-	-	-	-	-
T_5, MT(+R)-Chickpea	-	-	-	-	-	-	36.87	1.75	127.5	1282.7	2786.0	31.5
T_6, MT(+R)-Linseed	49.90	6.70	6.33	842.8	1387.2	37.79	-	-	-	-	-	-
T_7, CT(+R)-Chickpea	-	-	-	-	-	-	38.16	1.79	127.4	1340.1	2858.2	31.9
T_8, CT(+R)-Linseed	54.06	6.83	6.43	890.2	1449.1	38.05	-	-	-	-	-	-
SEm±	1.08	0.15	0.15	21.5	30.3	0.10	0.82	0.04	3.0	26.9	55.7	0.1
LSD (P= 0.05)	3.73	0.51	NS	74.3	104.8	0.36	2.82	0.14	NS	93.1	192.8	0.2

CT, Conventional tillage; MT, Minimum tillage; +R, With crop residue; -R, Without crop residue.

Table 3 Effect of conservation agriculture practices on soil organic carbon and nutrient availability in teak + bael-based agroforestry system (Pooled data of two years)

Treatments	Soil OC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available S (kg/ha)	Zn (mg/kg soil)	Fe (mg/kg soil)	Cu (mg/kg soil)	Mn (mg/kg soil)
T_1, CT (-R)-Chickpea	0.44	155.0	9.02	182.7	14.45	0.54	5.63	0.50	6.73
T_2, CT (-R)-Linseed	0.41	151.0	8.56	181.3	13.95	0.52	5.58	0.47	6.54
T_3, MT(-R)-Chickpea	0.45	164.0	8.86	177.4	14.75	0.58	5.96	0.52	6.88
T_4, MT (-R)-Linseed	0.45	159.5	8.22	184.6	14.65	0.57	5.80	0.51	6.79
T_5, MT(+R)-Chickpea	0.57	190.0	10.14	193.7	17.15	0.67	6.65	0.59	7.21
T_6, MT(+R)-Linseed	0.55	179.5	9.60	191.0	16.45	0.60	6.61	0.56	7.08
T_7, CT(+R)-Chickpea	0.53	176.0	9.15	187.8	15.55	0.58	6.17	0.55	6.94
T_8, CT(+R)-Linseed	0.51	171.5	9.06	188.3	15.00	0.56	6.13	0.53	6.90
SEm±	0.01	3.4	0.19	3.9	0.31	0.01	0.12	0.01	0.14
LSD (*P= 0.05*)	0.03	10.5	0.56	11.7	0.95	0.04	0.38	0.03	0.43

CT, Conventional tillage; MT, Minimum tillage; +R, With crop residue; -R, Without crop residue; OC, Organic carbon.

with crop residue-chickpea). However, both the treatments statistically comparable and significantly superior over to other treatments.

Increased yield attributing characteristics of linseed and chickpea may be attributed to better growth and development of these crops with conventional tillage with residue application over other treatments. Residue applications reduced the weed population, seed bank, and the crop competition for nutrients and water (Singh *et al.* 2022b). Kumar *et al.* (2013) and Parihar *et al.* (2016**)** also reported similar results in chickpea and other cereal crops. Residue retention increases the soil's biological properties and organic carbon which enhances crop growth (Ram *et al.* 2016, Meena *et al.* 2023).

Soil chemical properties: The application of crop residue with minimum tillage significantly improves the soil organic carbon and nutrient availability (Table 3). Compared to treatment with conventional tillage without residue application, 20.45–34.14% higher soil organic carbon was observed with residue application irrespective of the tillage treatment. Similarly, nitrogen availability increased from 151 kg/ha (T_2-CT (-R)-Linseed) to 190.0 kg/ha (T_5-MT (+R)-Chickpea), phosphorus from 8.22–10.14 kg/ha, potassium from 177.4–193.7 kg/ha, respectively. Similarly, residue application with minimum tillage in chickpea and linseed was observed with significantly higher available S, Zn, Fe, Cu, and Mn availability. However, this increment in the soil nutrient availability is not due to two-season residue application but due to the cumulative effect of the residue application of crop and tree leaf litter addition in the previous years. The increase in the soil organic carbon and nutrient availability in surface soil under the conservation agriculture practice is by the other studies (Malecka *et al.* 2012, Jat *et al.* 2018). Das *et al.* (2014) also reported the increased soil organic carbon with conservation agricultural practices due to gradual accumulation of organic matter in the soil.

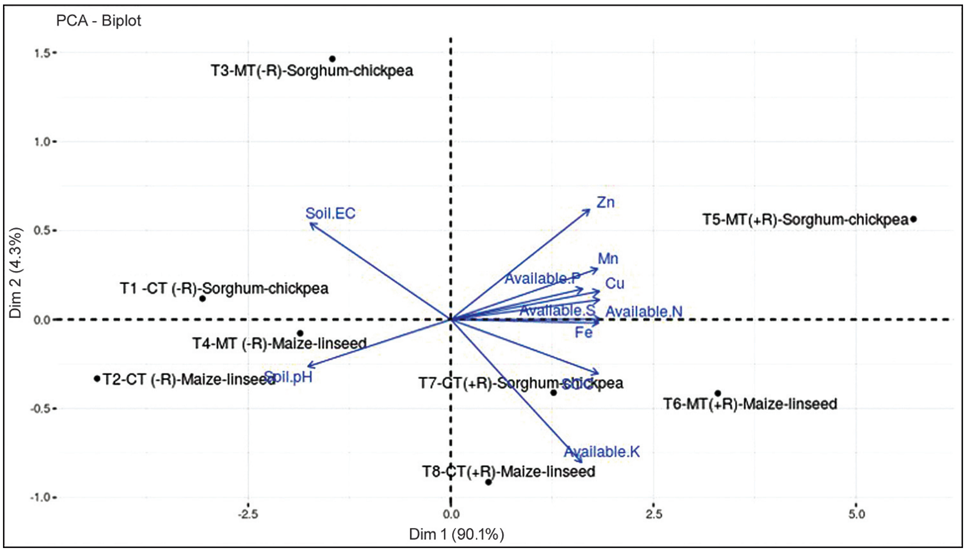

Fig. 2 PCA biplot analysis of soil nutrient availability as affected by the different tillage and residue treatments in teak+bael-based conservation agroforestry. CT, Conventional tillage; MT, Minimum tillage; +R, With crop residue; -R, Without crop residue.

PCA biplot and correlogram analysis: PCA biplot analysis of soil chemical properties revealed that soil organic carbon and nutrient availability is more with residue application with minimum tillage in sorghum-chickpea and maize-linseed cropping systems (Fig. 2). Correlogram of soil chemical properties showed significant positive correlation among

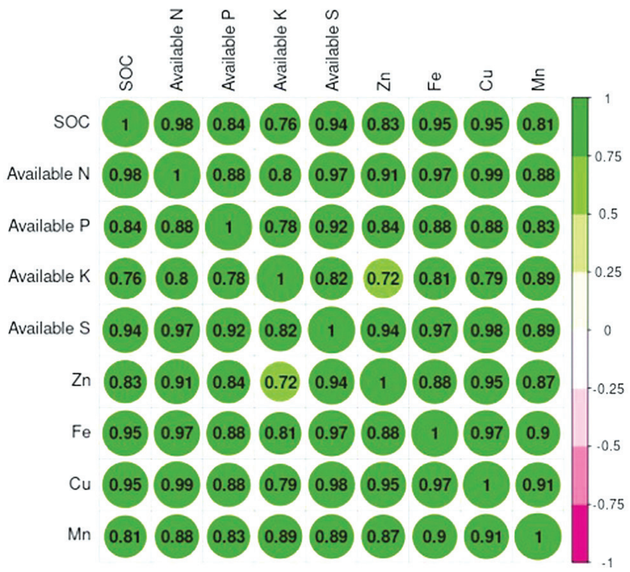

Fig. 3 Correlogram showing correlation between different parameters of soil chemical properties. SOC, Soil organic carbon.

most of the soil nutrients. Soil organic carbon has a significant positive correlation with all the macro- and micro-nutrients available in soils (Fig. 3). Our findings align with those of Kumar *et al.* (2014), who observed a significant positive correlation between organic carbon (OC) and other nutrients. Similarly, Nweke and Nnabude (2014) reported a strong positive correlation (r = 0.96) between nitrogen availability and soil organic carbon in tropical agro-ecosystems.

The study highlights the potential of integrating conservation agriculture practices within a teak + bael-based agroforestry system to improve crop yield and soil health in the Bundelkhand region. Residue retention accentuated the growth and yield of linseed and chickpea significantly, irrespective of tillage method, while also enhancing soil organic carbon (20.45–34.14% higher over no-residue retention) and nutrient availability, including nitrogen, phosphorus, potassium, and micronutrients. The findings indicate that combining agroforestry with conservation agriculture practices not only increases crop yields (14–20% higher yield as compared to conventional agricultural practices in teak + bael-based agroforestry system) but also contributes to soil fertility and long-term sustainability. The integration of trees on farmland can help address the shortage of crop residues in conservation agriculture. Furthermore, future research should prioritize the development of region-specific conservation-agroforestry models tailored to diverse agro-climatic conditions. Additionally, efforts should be directed toward optimizing residue retention practices by considering the quantity and quality of residues contributed by both tree and crop components within the system.

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