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Soil nutrient dynamics under poplar-based agroforestry: A comparative study in north-western India

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Abstract
Agroforestry system integrates woody perennials with agricultural crop and/or livestock. The system is being increasingly acknowledged for its potential to improve soil quality and productivity as compared to monoculture. The present study investigated the impact of poplar-based agroforestry system on soil quality to adjacent monoculture cropping of cucurbits and baby corn at the Punjab Agricultural University, Ludhiana, over the period of 2020 and 2023. In 2020, the study assessed the soil beneath a five-year-old poplar plantation intercropped with cucurbits, whereas in 2023, the focus was on baby corn grown under a two-and-a-half-year poplar plantation. Soil samples were taken at three different depths (0-15 cm, 15-30 cm, and 30-45 cm) in both the agroforestry and monoculture systems. The physical and chemical properties of soil were analysed. The study revealed that the soil pH was higher in open conditions (8.3 in sole cucurbits and 8.0 in sole baby corn) compared to poplar-based system (8.2 in intercropped cucurbits and 7.6 in intercropped baby corn). Additionally, the agroforestry system exhibited higher levels of electrical conductivity (dS/m), organic carbon (%), and availability of nitrogen (kg/ha), phosphorus (kg/ha), and potassium (kg/ha) at all sampled depths. The improvement in soil characteristics is attributed to the increased biomass input from both tree and crop components, enhanced nutrient cycling, and reduced soil disturbance. The findings underscore the potential of poplar-based agroforestry system to significantly enhance soil quality and fertility in the region.

Keywords: Nutrient analysis, sustainable, agroforestry, soil quality, fertility

Introduction
Soil quality is the soil's ability to support plant growth, recycle nutrients, filter water, and sustain ecosystem health within its ecological and land-use limits. It serves as a sensitive indicator for assessing soil fertility and dynamic changes in soil management (Yan *et al.*, 2024) [1]. Maintaining soil quality is essential for sustaining agricultural productivity in India, especially in the face of increasing demands for food production practices (Chattopadhyay *et al.*, 2017) [2]. Punjab's intense rice-wheat monoculture has significantly altered soil nutrient dynamics. In this context, agroforestry systems have emerged as a promising approach to improving soil quality and agricultural sustainability. Agroforestry systems are cropping practices which integrate woody perennials with agricultural crops and/or livestock on the same unit of land. These systems provide multiple benefits, including increased soil fertility, nutrient cycling, carbon sequestration. The tree component involved in these systems play a vital role in enhancing the overall health of soil.

Thin crowned poplar (*Populus deltoides* Bartr. ex Marsh.) is a fast-growing, multipurpose tree species that is widely integrated into agroforestry systems in North-Western India. Raised mostly on field boundaries or in blocks, poplar is known to pose less competition to the associated crops. It is a winter deciduous tree, shedding its leaves during November and December. Upon decomposition, the leaf litter releases nutrients, enhancing the organic matter and consequently improving the quality of soil. In addition to litterfall, by nutrient pumping and root turnover, poplar positively influences the physical, chemical and biological properties of soil (Singh and Sharma, 2007) [3].

In contrast to resource-exhaustive agriculture, agroforestry is a natural resource-conserving system having immense potential for crop diversification. Wheat is the most common intercrop under poplar-based agroforestry, followed by sugarcane, turmeric, sorghum, mustard, berseem fodder, onion, potato, and maize (Banoo *et al.*,2021) [4]. Growing different crops under Poplar in agroforestry system not only helps in restoring but also maintains the productivity of soil while increasing its profitability.

Members of plant family Cucurbitaceae are referred to as cucurbits, with Pumpkin and squashes being its major vegetable crops. Pumpkins fall into the category of monoecious plants with sprawling vines. Squashes, on the other hand, are cultivars that produce edible immature fruits with soft skins. Baby corn (*Zea mays* L.) refers to the unfertilized maize female ears picked 1-2 days after silk emergence.

Both of these crops can be considered a suitable option for crop diversification and can be screened under a poplar-based agroforestry system. However, a very few studies have been carried out in this context. Thus, the present study analysed different soil parameters under poplar based agroforestry system in comparison to sole cropping of Cucurbits and Baby corn. It will provide insights for understanding the influence of poplar on soil properties which enhances fertility status of the soils.

Materials and Methods

The study was conducted in the Research Area of Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana (30.54°N latitude, 75.48°E longitude and 247 MSL). Climate of the region is subtropical and represents central agro-climatic zone of the state, receiving an average annual rainfall of 500-750 mm. Covered by Indogangetic alluvium, the region is characterized by deep, well-drained soils. The region's soils primarily consist of Inceptisols followed by Entisols (Singh and Sharma, 2007) [3]. The block plantation of clone L-47 of poplar with spacing 8 × 2.5 m (N-S direction row spacing) with cucurbits as intercrop was selected for the study in Rabi 2019-20 when the poplar was of 5 year age at January 2020. In 2023, site selected for study was a two-and-a-half-year poplar block plantation (Clone L-47) with the same spacing, intercropped with baby corn. In control plots, sole crop was grown without trees.

Five random spots were selected for depth-wise (0-15, 15-30, and 30-45 cm) collection of soil samples in each replication using post hole auger and a composite sample was prepared from each depth. Soil samples were also taken from the sites where sole cucurbits and sole baby corn was grown. After air-drying, the soil samples were thoroughly crushed and passed through a 2 mm stainless steel sieve. Soil samples were analysed for texture, pH, electrical conductivity (EC), organic carbon (OC), and available N, P, and K. The texture of soil from experimental site was determined in the laboratory by specific gravity hydrometer method. On the basis of hydrometer analysis, soil was categorised into one of the classes i.e. sand, silt and clay. The soil pH and electrical conductivity were determined in soil: distil water suspension (1:2) using pH meter and electrical conductivity meter as outlined by Jackson (1973) [5]. Alkaline potassium permanganate method (Subbiah and Asija, 1956) [6] was used to estimate available nitrogen. The Walkley and Black method (1934) [7] of rapid titration was used to determine soil organic carbon, Olsen method for available phosphorus (1954) [8] and Merwin and Peech method (1951) [9] for determining for available K in the soil samples.

Van Bemmelen factor of 1.724 is commonly used in soil organic matter studies based on the assumption that humified organic matter of soil contains approximately 58% C. By multiplying total organic carbon (%) of soil by this factor, we calculated the organic matter (%) (Nelson and Sommers, 1982) [10].

Karl Pearsson Correlation analysis between different soil properties both under Agroforestry and sole cropping system was conducted using R 4.3.2 statistics software (core package of the software) (R Development Core Team, 2023).

Results and Discussion

Soil texture

Soil texture of the experimental sites was found to be sandy loam with percentage of sand, silt and clay being 82.4%. 11.4% and 5.8% respectively.

Soil pH

The pH nature of soil was found to fall within the alkaline range in all the experimental plots. A general increase in pH values was noted with increasing depth. Highest soil pH was observed in soil under sole baby corn (8.47) in the depth 30-45 cm and the lowest in soil under Poplar + cucurbit agroforestry system in the depth 0-15 cm (7.62). Soil under both agroforestry systems exhibited a slightly acidic pH in comparison to respective monocultures. A potential explanation for the lower pH in these soils is the greater buildup of aboveground biomass and associated cation uptake by the tree component of agroforestry systems. In addition, the organic acids released from the leaf litter and root decay also contribute to lowering of soil pH. The finding was similar to the results of Singh *et al.* (2024) [11] who found higher soil pH under control treatment than coffee-based agroforestry system in Chhattisgarh.

Electrical conductivity (dS/m)

Electrical conductivity of soil (EC) is correlated with soil properties such as texture, cation exchange capacity (CEC), drainage conditions, organic matter content, soil salinity, and subsoil characteristics that affect crop yield. Electrical conductivity measurements of soil samples exhibited a progressive decrease with increasing depth. Soil samples from Poplar + cucurbits agroforestry system in the depth 0-15 cm had the maximum EC value (0.29 dS/m) while soil under sole baby corn in the depth 30-45 cm recorded the minimum EC value (0.14 dS/m). Higher EC values in agroforestry system are ascribed to addition and decomposition of litter, enriching mineral basic salts of the soil. Similar results have been reported by Singh *et al.* (2018) [12] who observed soil EC to be relatively higher under *Tectona grandis* agroforestry system as compared to the agricultural field devoid of trees.

Table 1: Soil properties under poplar + baby corn agroforestry and monoculture at different depths

Soil property		Depth of soil (cm)		
		0-15	15-30	30-45
pH	Under Poplar	8.22	8.31	8.47
	Open Conditions	8.32	8.43	8.51
Electrical conductivity(dS/m)	Under Poplar	0.24	0.19	0.16
	Open Conditions	0.19	0.17	0.14
Organic carbon (%)	Under Poplar	0.77	0.63	0.59
	Open Conditions	0.59	0.55	0.52
Available N (kg/ha)	Under Poplar	294.9	282.4	276.8
	Open Conditions	281.8	268.3	255.8
Available P (kg/ha)	Under Poplar	27.3	23.2	16.2
	Open Conditions	21.0	18.2	15.0
Available K (kg/ha)	Under Poplar	265.0	253.0	248.0
	Open Conditions	240.0	223.3	211.6
Organic matter (%)	Under Poplar	0.74	0.45	0.33
	Open Conditions	0.38	0.31	0.28

Table 2: Soil properties under poplar + cucurbits agroforestry and monoculture at different depths

Soil property		Depth of soil (cm)		
		0-15	15-30	30-45
pH	Under Poplar	7.62	7.75	7.84
	Open Conditions	8.00	8.12	8.24
Electrical conductivity(dS/m)	Under Poplar	0.29	0.25	0.23
	Open Conditions	0.21	0.19	0.17
Organic carbon (%)	Under Poplar	0.88	0.72	0.67
	Open Conditions	0.61	0.58	0.55
Available N (kg/ha)	Under Poplar	300.0	289.0	280.0
	Open Conditions	287.0	275.0	269.0
Available P (kg/ha)	Under Poplar	44.9	39.9	23.8
	Open Conditions	39.4	34.7	22.3
Available K (kg/ha)	Under Poplar	393.4	371.8	354.1
	Open Conditions	384.5	367.4	344.5
Organic matter (%)	Under Poplar	0.93	0.57	0.66
	Open Conditions	0.45	0.38	0.33

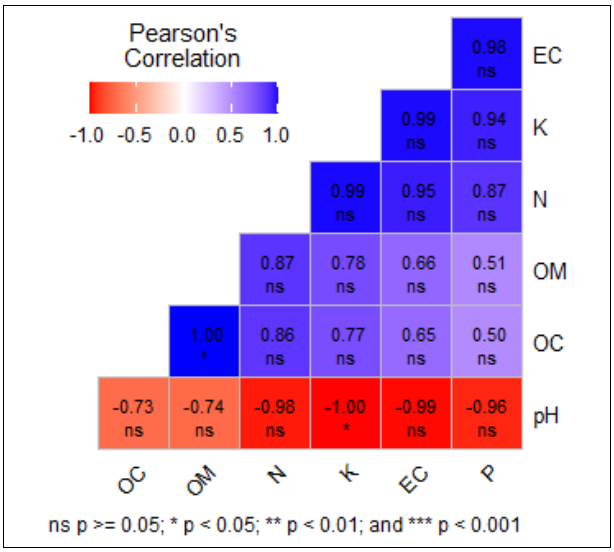
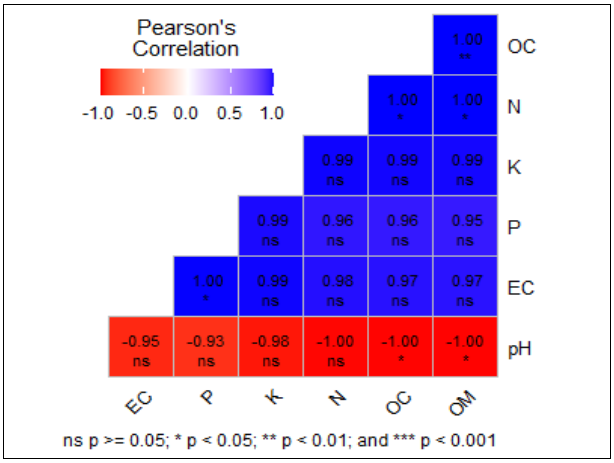


Fig 1: Correlation matrix for different soil parameters under Poplar based agroforestry



*OC: Organic carbon (%); N: Available Nitrogen (kg/ha); P: Available Phosphorus (kg/ha); K: Available Potassium (kg/ha); EC: Electrical conductivity(dS/m); OM: Organic matter (%).

Fig 2: Correlation matrix for different soil parameters under sole cropping system

Soil organic carbon (%)

The soil organic carbon content was found to vary with soil depth, decreasing with successive soil depths from 0-15 cm, 15-30 cm and 30-45 cm under all the experiment sites. A greater percentage of soil organic carbon build-up on the surface layers underneath the tree species could be attributed to the accumulation of litterfall on soil surface. Highest SOC was found in soil under Poplar + cucurbits agroforestry system in the depth 0-15 cm (0.88%) while the lowest in soil under sole baby corn in the depth 30-45 cm (0.52%). The SOC (%) improved underneath trees than sole crop in monoculture system. This may result from several processes including annual recycling of fine root biomass and root exudates, litter addition from trees and the decreased oxidation of organic matter under tree shade (Gill and Burman, 2002) [13]. The results were in conformity with the findings of Ghimire (2010) [14], Singh *et al.* (2018) [12] and Singh *et al.* (2010) [15].

Soil organic matter (%)

Soil organic matter varied with soil depth as well as with cropping system. A decreasing trend of organic matter with increasing soil depth was observed. Surface layers receive the organic crop residue which is decomposed by microbes. The highest value was observed in soil under Poplar + cucurbit agroforestry system in the depth 0-15 cm (0.93%) while the lowest in soil under sole baby corn in the depth 30-45 cm (0.28%). The agroforestry systems were found to be superior than monocropping systems in terms of soil organic matter (%).

Available Nitrogen in soil (kg/ha)

The available soil nitrogen (kg/ha) was influenced by presence of poplar as well as soil depths. The availability of nitrogen in the soil reduced as soil depth increased from 0-15 cm, 15-30 cm and 30-45 cm. Bhardwaj *et al.* (2001) [17] also noted this trend of available nitrogen with soil depth under a high-density poplar plantation. The lower nitrogen content in the subsurface samples is attributed to limited organic matter addition and reduced biological activity, which restricts mineralization in these lower soil layers. The maximum value recorded for available N in soil was found to be under poplar + cucurbit agroforestry system in the depth 0-15 cm (300.0 kg/ha) and minimum in sole baby corn in the depth 30-45 cm (255.8 kg/ha). Enhanced availability of nitrogen content in the soil under agroforestry system can be ascribed to the addition of organic matter in the soil by tree species. Similar findings were reported by Chaudhry *et al.* (2007) [16] after conducting studies on poplar based agroforestry systems.

Available Phosphorus in soil (kg/ha)

Pertaining to the data, soil available phosphorus was found to decrease with increase in soil depth. The phosphorus content in 0-15 cm soil depth revealed highest values. Under *Gmelina arborea* based agri-silvicultural system Swami *et al.*,(2008) [17] noted similar results of decrease in available phosphorus with soil depth. Among the two cropping systems, soil under agroforestry system had higher available phosphorus than soil in monoculture. The available P content in soil was found to be greatest under poplar + cucurbits agroforestry system in the depth 0-15 cm (44.9 kg/ha) and lowest in sole baby corn in the depth 30-45 cm (15.0 kg/ha). This might be due to increased activity of acidic phosphatase enzyme in presence of trees which promotes phosphorus solubilization. Tree roots contribute organic matter and foster a diverse microbial environment, enhancing enzyme activity. The results align with the findings of Kumari *et al.*,2025 [18] who reported available phosphorus to be higher under *Moringa oleifera* agroforestry system as compared to the monocropping system.

Available Potassium in soil (kg/ha)

The available potassium (kg/ha) in soil was found to vary with soil depth and cropping system. With increasing soil depth, available P in soil decreased in all the experimental sites. Thus potassium content was found to be conspicuously higher in the upper layer (0-15 cm) of soil in comparison to lower layers. Higher litterfall, fine root turnover and greater mobility of potassium at the surface layer of soil than the subsurface layer might have contributed to its increased quantity. Similar trend of potassium availability was also reported by several investigators like Bhardwaj *et al*., 2001 [19] and Swamy *et al.*, 2006 [20]. Available K content was observed to be the highest under poplar + cucurbits agroforestry in the depth 0-15 cm (393.4 kg/ha) and lowest in sole baby corn in the depth 30-45 cm (211.6 kg/ha). This might be due to increased activity of acidic phosphatase enzyme in presence of trees. The data pertaining to the available K content indicates that agroforestry systems exhibit a significantly higher level of potassium in the soil compared to monoculture. Potassium availability is increased in agroforestry systems compared to treeless farming due to enhanced nutrient recycling and the release of organic acids from accumulated organic matter, leading to higher potassium mineralization. Similar findings have been conferred by Singh *et al.*,2010 [15], Singh *et al.*,2018 [12] and Maharajan *et al.*,2024 [21].

Correlation analysis among soil properties

A Karl Pearson correlation analysis (using R programme) was performed to examine the relationships between soil physical and chemical properties under different cropping systems: poplar + cucurbits, poplar + baby corn, sole cucurbits, and sole baby corn. The analysis revealed positive correlations among all soil attributes except for soil pH, which showed a negative correlation with nutrients such as nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC), and organic carbon (OC). These findings align with previous studies by Yan *et al.* (2018) [22] in poplar and Anjali *et al.* (2023) [23] in teak. Singh and Mishra (2012) [24] also documented an inverse relationship between soil pH and nutrient availability.

Conclusion

The investigation revealed that soil nutrient status exhibited significant variations on account of cropping system as well as soil depth. Surface samples (0-15 cm depth) exhibited higher values for various parameters. From the study, it can be concluded that agroforestry systems are superior to sole cropping in enhancing soil quality. Both the agroforestry systems show higher fertility status than monoculture as they contain soils with higher available nutrient content. Apart from these, electrical conductivity and soil organic carbon content was also found to be higher in soils under agroforestry systems. Overall, improvement of soil quality by agroforestry system suggest that long term adoption of these systems may help mitigating the ill effects of rice-wheat monoculture and sustain soil health by improving various soil parameters.

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