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Enhancing and Maintaining Soil Health through Agroforestry

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SUMMARY

Integrating agroforestry with agriculture enhances soil health by improving its physical, chemical and biological properties. This sustainable practice supports nutrient cycling, carbon sequestration and soil fertility while reducing erosion and enhancing water retention. Agroforestry systems, such as those using Populus deltoides, increase organic matter and nutrient availability through litter fall and root interactions. These benefits contribute to sustainable agriculture, offering resilience against climate change and improving productivity. Studies highlight agroforestry's potential for restoring degraded lands and promoting ecosystem stability, making it a valuable tool for long-term agricultural sustainability and environmental conservation.

INTRODUCTION

Soil is a dynamic resource crucial for global biogeochemical cycling, ecosystem health, and sustainable food production (Du *et al.*, 2022). Unfortunately, many farmland soils are severely degraded due to annual row cropping, leading to pollution, greenhouse gas emissions, and biodiversity loss (Eddy and Yang 2022). The USDA defines soil health as the ability to support vegetation, animals, and human activities while enhancing output, carbon absorption, nutrient retention, and biodiversity conservation. Degradation is exacerbated by population growth and intensive agriculture (Gisladottir, 2005). Sustainable farming techniques like conservation farming and agroforestry address these challenges by minimizing disturbance, increasing biodiversity, and improving soil health. Agroforestry, in particular, enhances soil qualities by integrating trees with crops or livestock, thereby restoring soil health and promoting sustainability. Trees in agroforestry systems support soil organisms by providing habitats, offering a promising solution to combat soil degradation and ensure food security. Studies at CCS Haryana Agricultural University found higher soil enzymatic activities under agroforestry systems compared to sole cropping, highlighting agroforestry's benefits.

Enhancing soil quality and microclimate through agroforestry

Agroforestry improves soil quality and microclimates by integrating trees, which enhance nutrient cycling and capture leached and atmospheric nutrients. These systems efficiently use resources, increasing field capacity, organic matter, and soil carbon stocks while reducing bulk density. This boosts water retention, air circulation, groundwater recharge, and nutrient quality, particularly in arid regions. Litter accumulation enhances nutrient efficiency and microbial diversity, promoting a sustainable and productive agricultural system. Nitrogen-fixing trees in agroforestry enhance soil fertility and nitrogen cycling by decomposing leaf litter and adding organic matter. They help transfer nutrients to crop roots, improving soil nutrient content. Studies show that agroforestry systems increase soil fertility with higher phosphorus, potassium, and nitrogen levels compared to monocropping (Nath *et al.* 2015). Systems with trees like poplar and eucalyptus improve soil's physical and chemical properties, significantly increasing available nitrogen (365.2, 357.3, and 352.1 kg ha^{-1}) and soil organic carbon (0.70 and 0.72%). They also retain moisture and reduce soil temperature (Sirohi *et al.*, 2022). Integrating trees into farmlands enhances soil fertility, nutrient availability, and quality, contributing to sustainable agriculture.

Poplar based agroforestry system in semi-arid region of India

Populus deltoides is recognized as a crucial component in agroforestry systems for combating land degradation and ensuring sustainable biological production. It is extensively cultivated by farmers in North India, particularly in Punjab, Haryana and Uttar Pradesh, due to its fast growth, high market value and compatibility with other crops. The species enriches the soil by shedding large quantities of leaf litter, which enhances fertility by increasing soil organic carbon (SOC) and the availability of nitrogen (N), phosphorus (P) and potassium (K). This practice also generates additional revenue and employment opportunities for rural communities. As a winter deciduous tree, *Populus deltoides* produces substantial litter fall, further contributing to soil enrichment. Studies

have shown significantly higher levels of available soil nutrients in *Populus deltoides*-based agroforestry systems compared to conventional agriculture, primarily due to the decomposition of leaf litter and the addition of root residues from crops and trees (Figure 1, 2 and 3).

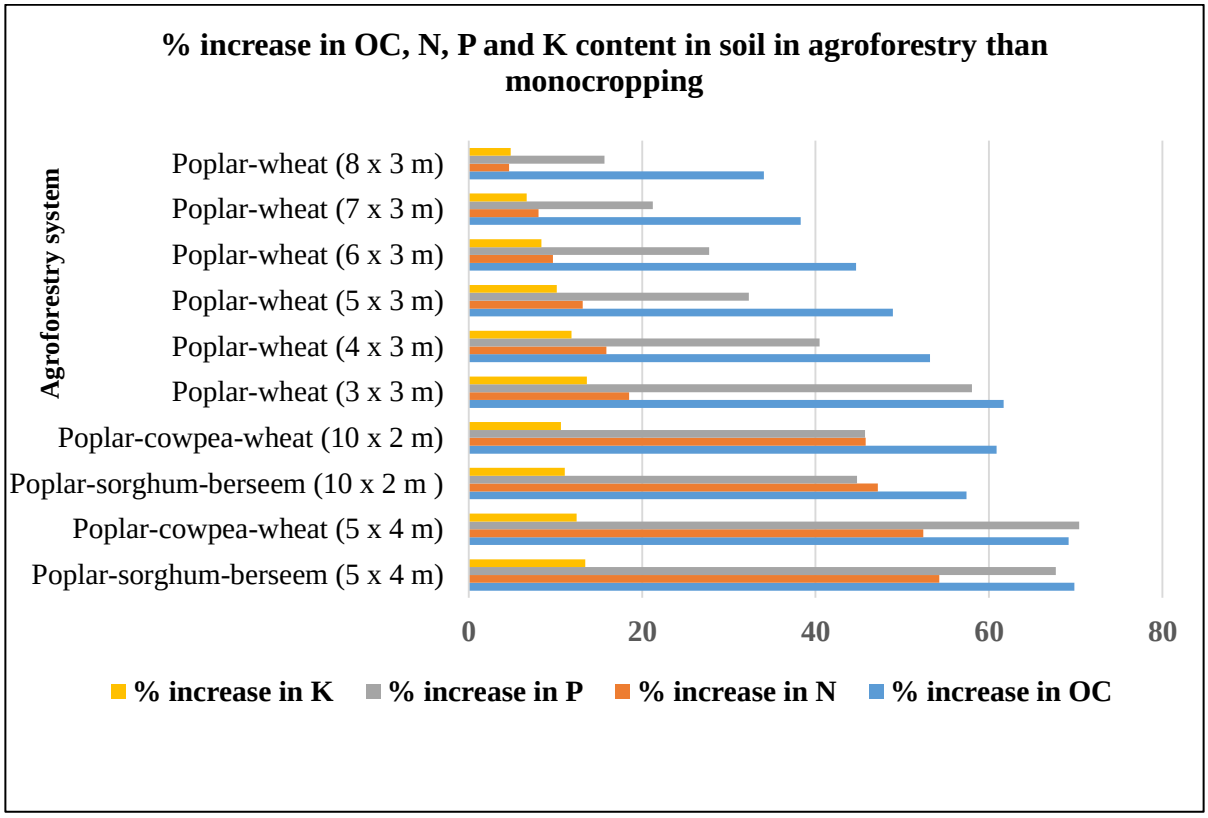

Figure. 1: Percentage increase in macronutrient status of soil as compared to control in various studies (Source: G. B. Rawale and S.B. Chavan-Unpublished data)

Figure. 2: Poplar based agroforestry system in Haryana (PC: G.B. Rawale)

Agroforestry for enhancing soil productivity and its management

Agroforestry systems offer several advantages over monoculture agriculture, including resource complementarity between trees and crops, leading to enhanced ecosystem productivity and functioning. Integrating trees with crops improves microclimate conditions, soil moisture retention, nutrient deposition and efficient nutrient cycling, resulting in improved soil health and agricultural yields. Studies have demonstrated significant increases in crop yields under tree canopies compared to open fields, with examples including higher maize grain yields and improved income from various intercropping systems. Furthermore, integrating fertilizer trees into agricultural land helps ensure food security, mitigates climate-related risks, and reduces the need for

exogenous fertilizers, thus lowering cultivation costs and enhancing income for smallholder farmers. Strategic management practices such as appropriate crop selection, tree-crop spacing, and precise fertilizer application can optimize resource utilization and promote sustainable agriculture in agroforestry systems. Additionally, integrating drought-tolerant trees and implementing micro-dosing fertilization techniques can further enhance land productivity and resilience to climate variability, offering a promising pathway for sustainable agricultural development.

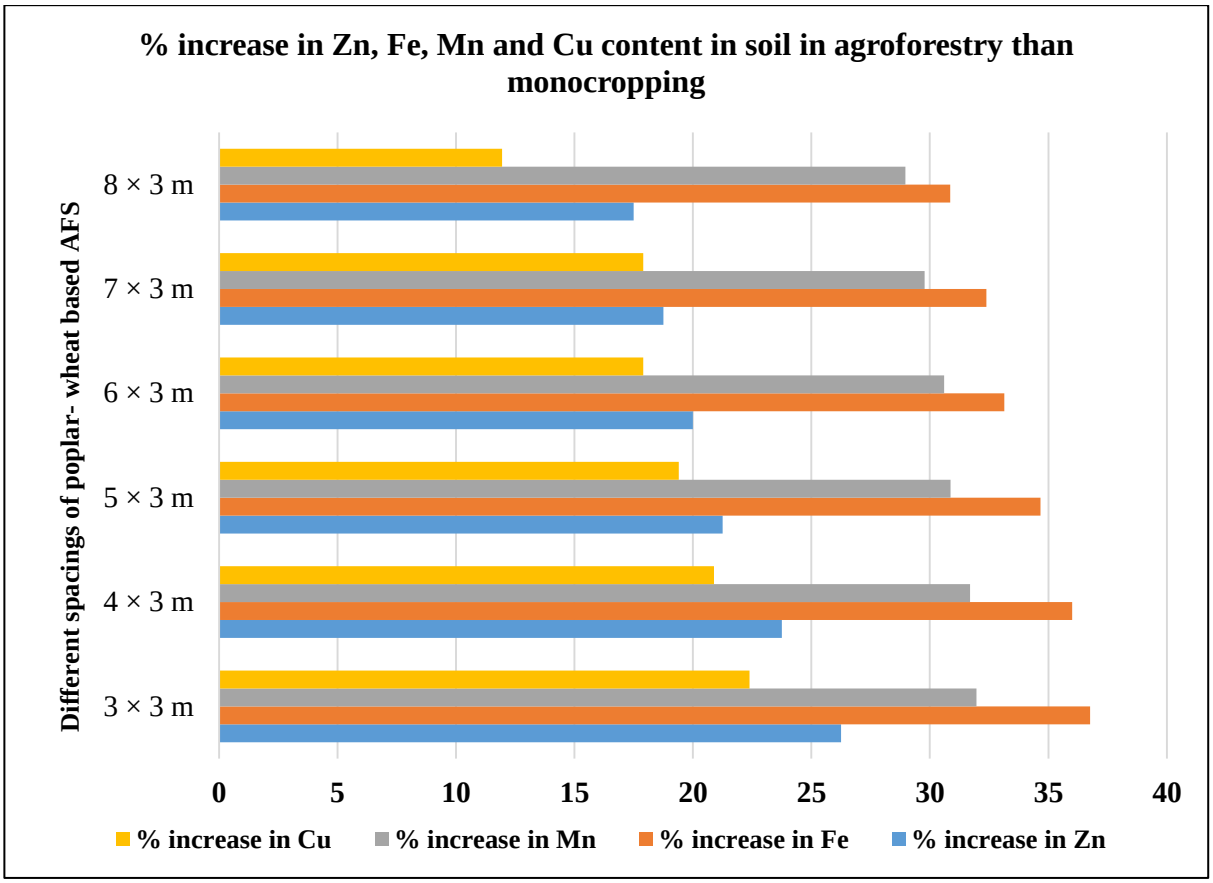

Figure. 3: Percentage increase in micronutrient status of soil as compared to control in various studies (data sourced from own doctoral research-Unpublished)

Agroforestry and soil erosion

Soil erosion poses a significant environmental threat, impacting soil fertility and ecosystem sustainability, with precipitation being a key factor. Agroforestry systems globally offer solutions, reducing runoff, preventing erosion, and optimizing land use, particularly in dry areas where they stabilize slopes. These systems mitigate erosion by adding organic matter through litterfall and pruning, acting as a physical barrier and enhancing soil cover. Biomass deposition from root turnover and litterfall supports soil organisms, boosting biological activity and soil stability. Agroforestry maintains essential forest cover, ensuring hydrological functions, while litter improves water quality by filtering runoff. Canopy cover and understorey vegetation enhance hydrological functions, reducing runoff and splash impact, and promoting infiltration. Biogenic channels and diverse root systems in agroforestry aid infiltration and preserve soil structure. Overall, agroforestry significantly reduces erosion rates and enhances soil health compared to monoculture crops.

CONCLUSION

Integration of trees with agricultural crops, known as agroforestry, offers numerous benefits for soil health and agricultural sustainability. Properly managed agroforestry systems improve soil structure, enhance soil biology, chemistry, and physics, and positively influence hydrological functions. By modifying microclimates, trees contribute to better water infiltration and reduce soil erosion and nutrient loss. Agroforestry also promotes soil microbial activity, nutrient cycling, and organic matter deposition, leading to overall soil quality improvement. Additionally, the incorporation of perennial components helps mitigate pollution and provides long-term environmental benefits. To encourage adoption, awareness among farmers and society about the

advantages of agroforestry is crucial. Overall, agroforestry offers a sustainable pathway for agricultural intensification and resilience in the face of climate change.

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