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Linking agroforestry and soil conservation practices: Shaping soil fertility in smallholder coffee systems of Africa

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Abstract

Smallholder coffee systems in the humid tropics of Central Africa are increasingly vulnerable to soil degradation, necessitating a transition towards regenerative agroecology. This study investigated how agroforestry shade levels and soil conservation practices interact to shape soil fertility across two Agroecological Living Labs (ALL): Kabare-Biega, DR Congo (n = 75), and Giheta, Burundi (n = 90). Using the Land Degradation Surveillance Framework (LDSF), topsoil (0–20 cm) was sampled with the Y-frame technique. Samples were analysed for soil organic carbon (SOC), total nitrogen (TN), available phosphorus (P), and soil pH. Statistical significance was determined using ANOVA and Tukey's HSD tests ($p < 0.05$).

Results showed that agroforestry structure and management practices significantly differentiated soil health outcomes between the two sites. In Kabare-Biega, shade intensity was the primary driver of fertility; SOC content was significantly higher in high-shade plots (4.2 %) than in low-shade systems (2.8 %). Available P also increased under high-shade conditions, while soil pH remained stable across the shade gradient (5.4). In the Giheta ALL, the synergy between canopy cover and mulching was decisive. The combination of high agroforestry levels and mulching yielded the highest SOC (4.01 %) and TN (0.29 %), significantly outperforming the bare soil plus low agroforestry control (SOC: 1.98%; TN: 0.14 %). In Giheta, however, available P and soil pH showed no significant variation across treatments, with P ranging narrowly from 2.1 to 3.8 mg kg ^{1} and pH fluctuating between 5.1 and 5.7.

These findings suggest that while canopy shade provides a baseline for organic input, ground-level conservation such as mulching is essential to double carbon and nitrogen stocks in degraded landscapes. We conclude that sustainable intensification in Central African coffee systems requires site-specific agroecological packages: optimising shade canopy in DR Congo to drive P availability and SOC, while integrating intensive mulch management in Burundi to overcome nutrient limitations. These insights are vital for transitioning towards resilient, climate-smart smallholder food systems in the humid tropics.

Keywords: Agriculture, Central Africa, coffee agroforestry, mulching, soil organic carbon

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