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"Reconcile land system changes
with planetary health"

Conceptualizing the restoration of nutrient and carbon stocks and their seasonal provision to meet crop demand

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Abstract

This study outlines pathways to restore soil nutrient and carbon stocks, while supplying crop-specific organic matter and nutrients throughout the growing season, and addresses the economic, logistical, and both *in situ* and *ex situ* challenges faced by African smallholder farmers.

Evidence shows severely depleted nutrient and carbon stocks in African soils, limiting soil health and crop productivity. The problem is twofold: low total reserves and poor nutrient availability at critical crop stages. We present process-based models for three African smallholder farms — defined by distinct soil types, climates, and resource availability — to quantify / optimise immediate nutrient and carbon availability and to restore soil nutrient and carbon stocks.

Beginning with soil nutrient and organic carbon stock assessments, we simulate mineral and organic strategies to meet crop-specific demands while rebuilding reserves. Balanced applications of macronutrients (N, P, K) and micronutrients via mineral and organic fertilisers overcome single-element limitations, enhance rhizobia performance in legume rotations, and sustain yields. Complementary organic inputs — on-farm residues (livestock manure, crop residues, household organic waste) and *ex situ* materials (market, slaughterhouse, and human waste) — supply nitrogen and carbon but only 20–40 % of crop nutrient demands, underscoring the need for mineral fertiliser supplementation.

We evaluate forage and alley legumes to boost nitrogen fixation and annual carbon inputs, offsetting typical losses of 2–10 t ha ^{1} yr ^{1} (humus decomposition and export of organic matter). We include liming for pH correction and the use of rhizobia inoculants or improved legume seed to ensure effective biological fixation, and assess agroforestry interventions for additional carbon sequestration.

Finally, we introduce a decision-support tool that integrates soil test data, remote-sensing indicators and farmer feedback to plan and monitor nutrient and carbon budgets, delivering actionable guidelines to rebuild soil health and sustain smallholder productivity across diverse economic contexts.

Keywords: Decision-support tool for nutrient and carbon budgeting, integration of organic and mineral *in situ* and *ex situ* inputs

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