An exploratory pre-planting and post-harvest assessment of short-term soil-chemical changes within a shrub–cereal–legume intercropping experiment in western Kenya

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ABSTRACT

Poor soil fertility, characterized by soil acidity, low organic carbon and nutrient imbalances, constrains smallholder crop production in western Kenya. This exploratory study characterized soil-chemical changes between pre-planting and post-harvest sampling within a field experiment comprising sole crops and two- and three-component shrub–cereal–legume intercrops under rainfed, minimum-tillage and low-external-input management. The experiment comprised 12 treatments arranged in three blocks. However, soil subsamples collected in a zig-zag pattern across the treatment plots were composited within each block, resulting in an effective sample size of three paired block-level observations and precluding assessment of treatment-specific soil effects. After one cropping season, mean soil pH changed from 4.63 to 5.20 and soil organic carbon from 1.09% to 1.78%. Available phosphorus changed from 11.37 to 17.07 mg kg^{-1} and exchangeable potassium from 95.75 to 132.99 mg kg^{-1}, whereas total nitrogen, exchangeable calcium and EDTA-extractable zinc decreased numerically. None of the paired differences was statistically significant at $p < 0.05$, and all 95% confidence intervals included zero, reflecting substantial uncertainty associated with the small sample. Because no independently sampled temporal reference was included, the findings represent experiment-wide temporal associations rather than treatment-specific effects. Nevertheless, the contrasting estimates demonstrate why regenerative performance should be evaluated across multiple soil indicators rather than inferred from a single property. They provide preliminary evidence of short-term soil dynamics and generate hypotheses concerning soil acidity, carbon cycling, nutrient redistribution and adaptive nutrient stewardship. Treatment-specific sampling, appropriate temporal controls, greater replication, multi-season monitoring, plant-tissue analysis, nutrient budgets and integrated field-based soil-health assessments are required to test the observed patterns and evaluate the regenerative potential of shrub–cereal–legume intercropping.

Keywords: Camphor Basil; Composite Soil Sampling; Exploratory Assessment; Intercropping; Nutrient Dynamics; Soil Organic Carbon; Western Kenya.

I. INTRODUCTION

Soil degradation constrains sustainable crop production in sub-Saharan Africa, particularly where continuous cultivation, limited organic-resource inputs and nutrient removal exceed replenishment (Sanchez, 2002; Vanlauwe et al., 2010). In the Upper Midland zones of western Kenya, high rainfall, erosion, leaching and prolonged cultivation contribute to soil acidity, low soil organic carbon and nutrient imbalances (Gudu et al., 2005; Jaetzold et al., 2005; Kihara et al., 2020). Locally adapted, biologically based practices may help restore soil functions, but their performance must be evaluated using multiple soil indicators rather than yield or carbon alone (Tittonell, 2014; Lehmann et al., 2020). Soil fertility is an important chemical dimension of soil health and reflects the soil's capacity to supply nutrients and support plant growth. It is influenced by soil acidity, organic carbon and the availability and balance of essential nutrients. The broader concept of soil health also encompasses physical and biological processes that regulate soil structure, water relations, biodiversity and ecosystem functioning (Bünemann et al., 2018; Lehmann et al., 2020). Consequently, restoring degraded soils requires management approaches that address these interacting dimensions rather than isolated soil properties.

Agroecology provides such a management framework by applying ecological principles to agricultural systems through diversity, recycling, biological interactions, resource-use efficiency and reduced dependence on external inputs Food and Agriculture Organization [FAO], 2018; Wezel et al., 2020). Regenerative agriculture shares

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many of these principles, although it lacks a universally accepted definition and is interpreted differently according to the objectives and interests of its proponents (Newton et al., 2020; Giller et al., 2021). For the purposes of this study, regenerative agriculture is interpreted as both a process and an outcome of agroecology, through which nature-based and low-disturbance management practices seek to restore soil functions, sustain crop production and minimize the risk of progressive nutrient depletion. The present study assessed selected chemical indicators of soil fertility rather than soil health or regenerative performance in its entirety. Intercropping was the principal agroecological practice examined within this broader regenerative framework. Intercropping combines species with different canopy structures, rooting patterns and nutrient-acquisition strategies, potentially improving resource-use and land-use efficiency (Hauggaard-Nielsen et al., 2008; Li et al., 2014). Cereal–legume systems may also support biological nitrogen fixation, soil cover and nutrient cycling, although outcomes depend on the species, soil conditions, climate and management practices involved (Giller et al., 2011; Lithourgidis et al., 2011; Xue et al., 2016; Maitra et al., 2021). Less is known about intercropping systems that integrate a semi-perennial shrub with cereal and legume crops, particularly under minimum tillage, spatially variable soil conditions and low external inputs.

Camphor basil (Ocimum kilimandscharicum) is an aromatic East African shrub with ecosystem-service and livelihood potential (Chumba et al., 2026). Its integration into food-crop fields provides a shrub component within mixed-species cropping arrangements. However, determining its effects on soil properties requires treatment-specific sampling. Because soil samples in the present study were composited at block level, the study neither tests the independent effect of camphor basil nor compares soil responses among the 12 crop treatments. Instead, it provides an exploratory description of block-level soil-chemical changes across the intercropping experiment after one cropping season. Improvement in one soil property does not necessarily imply improvement in soil fertility or soil health as a whole. Crop growth and biomass removal may coincide with nutrient uptake, redistribution or loss, while high rainfall can move mobile nutrients within or below the sampled soil profile. An exploratory multi-indicator assessment can therefore identify potentially important patterns and nutrient-management questions for subsequent investigation, provided that the observed patterns are not interpreted as causal treatment effects.

1.1 Statement of the Problem

The main problem addressed by this study is the limited empirical evidence on short-term soil-chemical changes within shrub–cereal–legume intercropping systems under the acidic, high-rainfall and low-external-input conditions of western Kenya. Existing assessments frequently emphasize individual carbon and nitrogen indicators without examining concurrent changes in soil acidity and essential macro- and micronutrients. This evidence gap limits multidimensional evaluation of soil-fertility responses and may obscure potential nutrient-management trade-offs within intercropping systems intended to contribute to regenerative agriculture.

1.2 Research Objectives

This exploratory study aimed to:

i. Describe pre-planting and post-harvest values for soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium and EDTA-extractable zinc in block-level composite samples.
ii. Estimate the direction and magnitude of change in each indicator between the two sampling periods.
iii. 3. Examine contrasting responses across the indicators to identify soil-fertility patterns and nutrient-management questions for more rigorous investigation.

II. METHODOLOGY

2.1 Study Area

The field experiment was conducted during the 2023 long-rains cropping season at Muhudu in Vihiga County, western Kenya. The site lies within the Upper Midland 3 (UM3) agroecological zone adjacent to the Kibiri section of Kakamega Forest. Vihiga County is located approximately between longitudes 34°30′ and 35°00′ E and latitudes 0°00′ and 0°15′ N. The area receives bimodal rainfall averaging approximately 1,800–2,000 mm annually, with mean daytime temperatures of approximately 24°C (Jaetzold et al., 2005). High population density, small landholdings, and continuous cultivation characterize the local farming system, in which maize–legume intercropping is widely practised. The experimental period was characterized by substantial rainfall, with 1,549.9 mm recorded between April and September across 143 rainy days.

2.2 Experimental Design and Treatments

The soil assessment was embedded within a broader field experiment evaluating the agronomic performance and ecosystem-service potential of shrub–cereal–legume intercropping systems. The experiment comprised 12 treatments arranged in a randomized complete block design with three blocks. Each treatment plot measured 20 m² (5 m × 4 m). The treatments included sole crops, two-component intercrops and three-component intercrops involving

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camphor basil (*Ocimum kilimandscharicum* Gürke), maize (Zea mays L.), NERICA rice (Oryza sativa L.), cowpea (*Vigna unguiculata* [L.] Walp.), soyabean (*Glycine max* [L.] Merr.) and common bean (*Phaseolus vulgaris* L.).

Although the treatments were replicated agronomically, soil sampling was conducted at block rather than treatment-plot level. No treatment-specific soil samples were collected; consequently, soil responses are evaluated as experiment-wide changes across the three paired block composites. Table 1 presents the treatment composition to provide the agronomic context of the soil assessment. Crop establishment, productivity and intercropping performance have been reported separately (Chumba et al., 2026). The two-component intercrops were established using a replacement-series arrangement, in which the population of one component was partially reduced to accommodate the second crop (Andersen et al., 2007; Maitra et al., 2021). The three-component treatments were established using an adapted Mbili-Mbili paired-row arrangement commonly applied in cereal–legume systems in Kenya (Mucheru-Muna et al., 2010).

Table 1

Description of the experimental treatments

Treatment	Crop combination	Cropping-system category
T1	Camphor basil + NERICA rice	Two-tier intercrop
T2	Camphor basil + maize	Two-tier intercrop
T3	Soyabean + NERICA rice	Two-tier intercrop
T4	Soyabean + maize	Two-tier intercrop
T5	Camphor basil + maize + cowpea	Three-tier shrub-based intercrop
T6	Soyabean + maize + cowpea	Three-tier crop intercrop
T7	Camphor basil	Sole crop
T8	Soyabean	Sole crop
T9	Cowpea	Sole crop
T10	NERICA rice	Sole crop
T11	Maize	Sole crop
T12	Maize + common bean + cowpea	Three-tier farmer-practice comparison

Note. NERICA = New Rice for Africa. T12 represented the local farmer-practice comparison. [Camphor basil = *Ocimum kilimandscharicum*; soyabean = *Glycine max*; cowpea = *Vigna unguiculata*; maize = *Zea mays*; and common bean = *Phaseolus vulgaris*.]

2.3 Crop Establishment and Field Management

Camphor basil seedlings were raised during the 2022 short-rains season at Shamiloli near the Kakamega Forest boundary. Healthy seedlings of relatively uniform height and vigor were selected and transplanted at the beginning of the 2023 long-rains season. Transplanting was undertaken concurrently with the sowing of the annual crop components. Maize, NERICA rice, cowpea, soyabean and common bean were established following locally recommended agronomic practices and appropriate spacing for the respective sole and intercropped treatments. All treatments were managed under rainfed conditions and minimum tillage. Crop residues were retained on the soil surface, and no soil-applied mineral fertilizer or synthetic pesticide was used during the experiment. Routine field operations, including weeding, were applied consistently across the experimental plots.

2.4 Soil Sampling

Soil sampling was conducted immediately before crop establishment on 14 April 2023 and immediately after harvest on 21 September 2023. The baseline samples represented a previously fallowed field, which may have retained spatially variable nutrient conditions or a residual fertility pulse. No fallow, no-crop or conventionally managed reference was sampled concurrently; temporal change therefore cannot be separated from seasonal conditions, natural soil processes, sampling variability or laboratory variability. Soil was collected from 0–15 cm depth following Anderson and Ingram (1993) and Okalebo et al. (2002). Each block served as one sampling unit. Multiple subsamples were taken in a zig-zag pattern between crop rows across all 12 treatment plots within each block and combined into one block-level composite. This produced three paired observations at each sampling date. Approximately 0.5 kg of each composite was transported to the Kenya Agricultural and Livestock Research Organization Soil Research Institute laboratory at Kibos for analysis. The sampling design characterized the overall soil-chemical transition across the intercropping experiment. Because treatment plots were pooled within blocks and no independently sampled temporal control was available, before-after differences are reported solely as uncontrolled field-level temporal associations.

2.5 Laboratory Analysis of Soil Chemical Properties

The soil samples were air-dried, crushed, and passed through an appropriate sieve before chemical analysis. Laboratory analyses followed the procedures described by Okalebo et al. (2002), unless otherwise specified. Soil pH

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was measured potentiometrically in a 1:2.5 soil-to-water suspension. Soil organic carbon was determined using Walkley-Black dichromate wet oxidation. Soil organic matter was calculated as organic carbon × 1.72, but this conventional factor may not represent site-specific organic-matter composition (Pribyl, 2010). Consequently, calculated organic matter is identified only as a derived descriptive value and is not analysed as an independent response. Total nitrogen was determined by Kjeldahl digestion, and available phosphorus was extracted using the Bray-1 procedure.

Exchangeable potassium and calcium were extracted using 1 M ammonium acetate (NH_4OAc). Their concentrations were subsequently determined using atomic absorption spectrometry. Zinc was extracted using 1% ethylenediaminetetraacetic acid and quantified by atomic absorption spectrometry following Moberg (2001). The soil indicators evaluated were therefore pH, organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium, and zinc.

2.6 Statistical Analysis

Given the effective sample size of three paired blocks and the absence of an independently sampled temporal control, p-values were treated as secondary summaries rather than confirmatory evidence. Raw paired mean differences and 95% confidence intervals were used as the principal effect estimates. For each soil property, block-level values were summarized by the pre-planting and post-harvest mean and range. The paired block difference was calculated as post-harvest minus pre-planting. Raw mean paired differences with two-sided 95% confidence intervals were used as the principal effect estimates because they retain the original measurement units. Two-sided paired t-tests were also calculated, but their p-values are treated as secondary and highly uncertain because the effective sample size was three pairs (df = 2). Statistical significance was defined as $p < 0.05$; failure to meet this threshold was not interpreted as evidence of no change. Soil organic matter was not tested independently because it was derived directly from organic carbon. Analyses were conducted using the retained block-level laboratory values. The original JMP/SAS output was unavailable at revision, so all paired calculations were reproduced directly from the reported block observations and checked for consistency with the manuscript. The analysis estimates temporal association only; it cannot isolate intercropping, camphor basil, crop diversity, minimum tillage, rainfall, crop uptake, residue inputs or other possible contributors.

III. FINDINGS & DISCUSSION

3.1 Findings

3.1.1 Baseline and Post-Harvest Soil Chemical Properties

Across the three paired block composites, the sample means changed in contrasting directions after one cropping season (Table 2). All 95% confidence intervals were wide and included zero. These estimates describe the three sampled blocks only and do not provide treatment-level or controlled causal comparisons.

Table 2

Block-level soil properties before planting and after harvest with paired effect estimates

Soil property	Pre-planting mean (range)	Post-harvest mean (range)	Mean paired difference (95% CI)	Relative change	p-value
Soil pH	4.63 (4.40 to 5.00)	5.20 (4.90 to 5.50)	+0.57 (−0.44 to 1.57)	—	0.1358
Organic carbon (%)	1.09 (1.03 to 1.21)	1.78 (1.58 to 1.93)	+0.69 (−0.01 to 1.39)	+63.3%	0.0513
Total nitrogen (%)	0.0105 (0.0030 to 0.0165)	0.0073 (0.0060 to 0.0090)	−0.0032 (−0.0240 to 0.0177)	−30.2%	0.5809
Available phosphorus (mg kg^{-1})	11.37 (8.67 to 16.38)	17.07 (14.45 to 20.25)	+5.70 (−11.23 to 22.64)	+50.1%	0.2844
Exchangeable potassium (mg kg^{-1})	95.75 (71.99 to 111.60)	132.99 (113.43 to 148.75)	+37.23 (−42.77 to 117.24)	+38.9%	0.1832
Exchangeable calcium (mg kg^{-1})	807.15 (612.14 to 939.27)	738.00 (473.15 to 922.35)	−69.15 (−225.43 to 87.14)	−8.6%	0.1973
EDTA-extractable zinc (mg kg^{-1})	23.94 (9.06 to 34.96)	8.04 (3.72 to 10.95)	−15.89 (−50.95 to 19.16)	−66.4%	0.1904

Note. n = 3 paired block composites; CI = two-sided 95% confidence interval for the raw paired mean difference; p-values are from paired t-tests with 2 degrees of freedom and are secondary descriptive summaries. Soil pH change is expressed in pH units. The organic-matter values derived as organic carbon × 1.72 were 1.88% before planting and 3.07% after harvest, but were not treated as an independent response. The largest positive sample estimate was observed for organic carbon (+0.69 percentage points; 95% CI: -0.01 to 1.39), whereas the largest proportional negative estimate was observed for EDTA-extractable zinc (-66.4%; raw difference -15.89 mg kg^{-1}; 95% CI: -50.95 to

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19.16). Soil pH, phosphorus, and potassium also increased numerically, while total nitrogen and calcium decreased numerically. None of the paired tests met $p < 0.05$, but the wide intervals and very small sample mean that non-significance cannot be interpreted as evidence of absence of change.

3.1.2 Interpretation of the Paired Estimates

The block pairs were not uniform. For example, phosphorus increased in two blocks but decreased in one, while zinc decreased sharply in two blocks and changed little in the third. This between-block heterogeneity generated wide confidence intervals. The results are therefore treated as descriptive, hypothesis-generating observations rather than confirmatory evidence of improvement, deterioration, or treatment effects. Rainfall during the experimental period: Monthly rainfall records for April–September 2023 indicated a cumulative total of 1,549.9 mm across 143 rainy days (Table 3). April recorded the highest monthly rainfall, at 596.5 mm, and the highest daily value, at 66.15 mm. July recorded the lowest monthly total, at 115.8 mm. These rainfall conditions provide important environmental context for interpreting possible nutrient redistribution and movement within or below the sampled soil layer.

Table 3

Monthly Rainfall, UM Vihiga, April–September 2023

Month	Total rainfall (mm)	Rainy days (n)	Highest daily rainfall (mm)
April	596.5	28	66.15
May	273.9	28	26.55
June	202.4	23	23.95
July	115.8	20	21.05
August	124.6	19	27.30
September	236.8	25	35.55
Total	1,549.9	143	—

Note. Source: Kenya Meteorological Department—Vihiga Rainfall Report 2023/2024, Reg. No. 8934213. The rainfall-recording station was approximately 15 km from the experimental field. These records describe the study period and do not represent a long-term climatological average.

3.2 Discussion

3.2.1 Soil Acidity and Carbon Responses

The paired block observations changed in contrasting directions during the season, but the uncertainty intervals were wide and all included zero. The data therefore neither confirm improvement nor establish absence of change. More importantly, the design cannot attribute any observation to intercropping, camphor basil or crop diversity. The discussion below considers plausible explanations only as hypotheses for future controlled investigation. Mean pH was 0.57 units higher after harvest, but the 95% confidence interval ranged from -0.44 to 1.57 units. Soil pH affects nutrient solubility, root growth and microbial activity (Marschner, 2012; Lehmann et al., 2020), so a persistent increase could be agroecologically relevant. In this study, however, seasonal processes, spatial variability, sampling position and analytical variation cannot be separated from management-related processes.

Plant uptake and recycling of base cations, rhizosphere activity and residue decomposition can influence pH (Hinsinger et al., 2003; Jobbágy & Jackson, 2004; Butterly et al., 2011). These processes were not measured; future studies should therefore incorporate conventionally tilled, fertilized, fallow and no-crop reference treatments sampled concurrently across multiple seasons. Soil organic carbon was 0.69 percentage points higher after harvest (95% CI: -0.01 to 1.39). Longer-term intercropping and agroforestry studies have reported carbon responses associated with root inputs and biomass management (Cong et al., 2015; Mugendi et al., 1999; Maier et al., 2023). Confirmation of regenerative performance here would require repeated treatment-specific measurements over several seasons, together with bulk density and carbon-stock estimates. Organic matter was obtained directly from organic carbon using the factor 1.72, but that conventional conversion can vary among soils and analytical contexts (Pribyl, 2010). Nevertheless, organic carbon is the primary carbon indicator in this paper; and the calculated organic-matter values remain invaluable as a descriptive metric.

3.2.2 Phosphorus, Potassium and Nitrogen Dynamics

Available phosphorus was 5.70 mg kg^{-1} higher after harvest, with a 95% confidence interval ranging from −11.23 to 22.64 mg kg^{-1}. Phosphorus availability in acidic soils can be influenced by pH, sorption reactions, root exudation and microbial transformations (Hinsinger, 2001; Richardson et al., 2009). Because these processes were not measured, one block showed a decrease, and the confidence interval encompassed zero, the observed increase should be interpreted as a positive numerical difference rather than conclusive evidence that intercropping significantly mobilised phosphorus.

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Exchangeable potassium was 37.23 mg kg⁻¹ higher after harvest (95% CI: −42.77 to 117.24 mg kg⁻¹), indicating a positive numerical difference. Potassium release from decomposing residues and enhanced nutrient cycling within the intercropping system are plausible explanations for this increase. However, because the confidence interval permitted both positive and negative underlying changes, and processes such as residue decomposition, crop uptake and leaching were not measured, these mechanisms remain hypotheses requiring further investigation.

Mean total nitrogen declined from 0.0105% before planting to 0.0073% after harvest—a reduction of approximately 30.2% or 0.0032 percentage points (95% CI: −0.0240 to 0.0177). Nitrogen decreased in two blocks but increased in one, suggesting spatially heterogeneous nitrogen dynamics. The overall decline may indicate that crop uptake and temporary microbial immobilisation exceeded short-term nitrogen contributions from biological fixation and residue decomposition. Thus, the findings indicate a short-term reduction in measured soil nitrogen rather than sustained nitrogen depletion. Longer-term, treatment-specific monitoring is needed to determine whether legume nitrogen fixation and organic-residue cycling eventually compensate for nitrogen removal by the crops..

3.2.3 Calcium and Zinc Responses

Exchangeable calcium was 69.15 mg kg⁻¹ lower after harvest (95% CI: −225.43 to 87.14 mg kg⁻¹). Crop uptake, leaching and redistribution are plausible processes in humid, acidic soils (Fageria & Baligar, 2008). However, these processes were not measured, and the confidence interval encompassed both decreases and increases. The concurrent numerical increase in soil pH and decrease in exchangeable calcium also demonstrates why no single soil indicator should be used to infer comprehensive soil regeneration. EDTA-extractable zinc was 15.89 mg kg⁻¹ lower after harvest (95% CI: −50.95 to 19.16 mg kg⁻¹). Two blocks showed decreases of approximately 24 mg kg⁻¹, whereas the third changed by only 0.40 mg kg⁻¹, indicating considerable spatial heterogeneity. The wide confidence interval and variable block responses do not provide conclusive evidence of zinc depletion. Increasing soil pH can reduce extractable zinc through enhanced adsorption and precipitation (Alloway, 2009), although crop uptake, nutrient redistribution, spatial sampling variation and laboratory analytical variation are also possible explanations. Moreover, because the baseline and post-harvest samples were analysed in separate laboratory batches, an analytical batch effect cannot be ruled out.

The baseline mean of 23.94 mg kg⁻¹ was substantially higher than the critical deficiency level of 1.17 mg kg⁻¹ reported by Zare et al. (2009) for EDTA-extractable soil zinc in maize using the Cate–Nelson procedure in a green house setting. Therefore, direct comparison should be made cautiously because critical values vary with the extraction method, soil properties, crop species and locally calibrated crop responses (Alloway, 2009). The field's previous management and inherent spatial variability may have contributed to the elevated baseline concentration, but specific influences, including possible residual nutrient or ash inputs, cannot be verified retrospectively. Accordingly, the observed zinc decline should be treated as a quality-control and nutrient-monitoring signal, requiring repeated soil testing using a consistent sampling and analytical method, accompanied by plant-tissue analysis and crop-response trials before diagnosing zinc deficiency or recommending zinc amendments.

3.2.4 Implications for Regenerative Soil Management

The observations illustrate the need for multidimensional soil monitoring for effective evaluation of regenerative performance. Numerical increases in pH, organic carbon, phosphorus and potassium occurred alongside numerical decreases in nitrogen, calcium and zinc. Because all intervals were wide, none of these patterns can be characterized as established improvement or depletion. Diversification, recycling, resource-use efficiency and biological synergy are central agroecological principles (FAO, 2018; Wezel et al., 2020). Through complementary rooting patterns, residue inputs, biological nitrogen fixation and rhizosphere interactions, diversified intercropping systems can enhance above- and below-ground nutrient cycling. The tested arrangements were designed around these established processes, while crop-yield and land equivalent ratio results reported separately provide treatment-level evidence of agronomic complementarity and land-use efficiency (Chumba et al., 2026). The experiment-wide soil responses are therefore consistent with nutrient-cycling processes expected in diversified cropping systems, although block-composite sampling did not permit the relative contribution of each treatment to be quantified.

A general management principle emerging from the literature is that soil carbon, acidity, macronutrients and micronutrients should be monitored together and that confirmed deficiencies should be corrected using locally validated approaches (Vanlauwe et al., 2015). For densely populated smallholder landscapes in western Kenya, intercropping remains worthy of controlled evaluation because land scarcity limits prolonged fallow. Future evaluation should pair treatment-specific soil sampling with crop productivity, residue management, input records and nutrient budgets so that ecological benefits and nutrient-export risks can be assessed together.

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IV. CONCLUSION & RECOMMENDATIONS

4.1 Conclusion

This exploratory before-and-after assessment documented contrasting soil-chemical changes across three paired block-level composite samples after one season within a shrub-based intercropping experiment. Mean soil pH, organic carbon, available phosphorus and exchangeable potassium were numerically higher after harvest, while total nitrogen, exchangeable calcium and EDTA-extractable zinc were lower. All 95% confidence intervals included zero. The results therefore describe preliminary patterns; they do not establish treatment effects or attribute the changes to intercropping or camphor basil; and do not establish a deficiency or justify an amendment. Considered alongside the separately reported crop-yield and land-use results, these observations strongly support further investigation of shrub–cereal–legume intercropping. They also show why soil-health assessment should consider acidity, carbon and nutrients together.

4.2 Recommendations

Future on-site studies should collect treatment-specific soil samples, use adequate replication and include concurrently sampled reference treatments across multiple seasons. This would allow the effects of individual intercropping systems to be assessed more reliably and help distinguish them from seasonal variation. Soil monitoring should track pH, organic carbon, nitrogen, phosphorus, potassium, calcium and zinc together. The numerical declines in nitrogen, calcium and zinc merit follow-up, particularly the zinc pattern. Nutrient-management decisions at the study site should be based on repeated soil testing, crop responses and locally validated recommendations.

Declaration of Interest

The authors declare that they do not have any known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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