CGIAR SUSTAINABLE FARMING

Integrated Soil Fertility Management Strategies for Resilient Soils in Ethiopia

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Contents

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Context

Soil fertility depletion and nutrient mining are critical challenges to sustainable crop production in Sub-Saharan Africa (SSA). Addressing these issues requires a multifaceted approach, including improved soil management practices, the use of organic fertilizers, and the adoption of sustainable agronomic practices. Integrated soil fertility management (ISFM) is one of the approaches to improving the yields of crops while preserving sustainable and long-term soil health and fertility through the combined application of fertilizers, recycling of organic resources, use of responsive crop varieties, and improved agronomic practices, which minimize nutrient losses and improve the nutrient-use efficiency of crops (Agegnehu and Amede, 2017; Vanlauwe et al., 2015). The fertility status of steep-slope cultivated lands has been depleted due to the loss of soil organic matter and nutrient reserves. The response of such soils to the application of nutrients is low, unless their fertility is restored through the adoption of an integrated soil-crop system for improved crop-nutrient response and yield (Minh et al., 2023).

Soil fertility depletion in Ethiopia is a severe issue driven by key factors like soil erosion, unsustainable farming practices, and inadequate use of fertilizers and organic matter. This leads to nutrient imbalances, soil acidification, and reduced crop yields, impacting food security. Studies have confirmed the annual nutrient depletion rates of up to 122 kg N ha^{-1}, 13 kg P ha^{-1}, and 82 kg K ha^{-1} at the national level (Haileslassie et al., 2005). The soil organic carbon (SOC) depletion rates in Ethiopia vary by region and land use, with a significant annual average loss of around 3 t ha^{-1} in the highlands (van Beek et al., 2018). Although organic residues, such as crop residues and animal manure, are crucial for maintaining healthy soils and enhancing fertility, about 85% of them are used for livestock feed and energy production, limiting their availability for soil amendment (Agegnehu and Amede, 2017). This competing use poses a challenge to sustainable agricultural practices, particularly in regions where access to alternative soil fertility inputs is limited.

Despite certain challenges, using farm-generated organic wastes, such as crop residues and manure, for soil fertility management can reduce a farmer's dependence on expensive inorganic fertilizers and offer a sustainable way to recycle waste materials. The main trade-off is the depletion of soil organic matter and subsequent long-term soil degradation in exchange for immediate, short-term economic survival and energy access. The use of crop residues and manure for immediate household energy needs and feeding livestock is a critical short-term economic activity. Balancing this trade-off often requires integrated approaches, such as combining the use of organic matter with mineral fertilizers, using biochar, and developing alternative energy and feed sources to ensure the success of the present and future needs. The main incentive for farmers to adopt ISFM practices is economic benefits. Therefore, for sustainable crop intensification in smallholder farming systems, developing soil and crop management strategies that enhance the efficiency of fertilizer use by integrating inorganic fertilizer with organic amendments and improved agronomic practices is required. This case study builds on ISFM field experiments in wheat and teff cropping systems in the highlands of Ethiopia, representing various soil types (e.g., Cambisols, Nitisols, Acrisols, and Luvisols), rainfall, and agroclimatic zones (warm sub-humid, tepid sub-humid, and tepid-moist).

ISFM Strategies

ISFM involves a combination of organic and inorganic fertilizers, improved crop varieties, and knowledge of local conditions to enhance nutrient use efficiency and boost crop productivity. Recent research findings have confirmed that the synergistic interaction effect of combining inorganic and organic fertilizers could result in significantly higher crop yields, compared to using inorganic fertilizers separately (Amede et al., 2021; Ndegwa et al., 2023; Paramesh et al., 2023). The synergistic effect of ISFM occurs when organic and inorganic fertilizers are combined, thereby improving soil health and crop productivity and generating an output greater than the sum of their individual contributions. This synergy enhances nutrient availability and uptake, increases crop yields and quality, and sustains long-term soil health and fertility by complementing the strengths of each nutrient source.

The organic and inorganic nutrient sources complement each other, where organic inputs improve soil physical properties and microbial activity, and inorganic fertilizers provide readily available nutrients. Despite the highest wheat and teff yields with the use of inorganic fertilizer alone, the growth and yield of both crops were significantly improved by the ISFM practices, which could be attributed to the overall enhancement in soil biophysical and chemical properties, nutrient use efficiency, and water retention capacity. The practice of ISFM not only improves soil fertility but also enhances and sustains biomass and grain yields in the long term, which may contribute surplus crop residues to livestock feed in addition to soil fertility.

Role of ISFM in Cereal Yield Improvements

Comparable crop yields were commonly achieved through the application of inorganic fertilizer alone on one hand and ISFM practices on the other hand. Applying the recommended NP fertilizer alone increased teff grain yield 2.5 times compared to the control (without any nutrients), followed by a yield increment of 2.1 times due to the application of 50% of the recommended inorganic fertilizer either with compost or vermicompost relative to the control. Similarly, applying the recommended inorganic fertilizer alone and 50% of the recommended inorganic fertilizer with 50% vermicompost resulted in wheat grain yield increments of 2.5 and 2.3 times, respectively, compared to the control (Figure 1). The ISFM approach confirms that partial replacement of inorganic fertilizer with organic fertilizers could result in a comparable yield to that obtained with the application of the full recommended N and P fertilizer doses alone. This is considered an alternative approach for increased and sustainable soil fertility and crop yields, while protecting the environment.

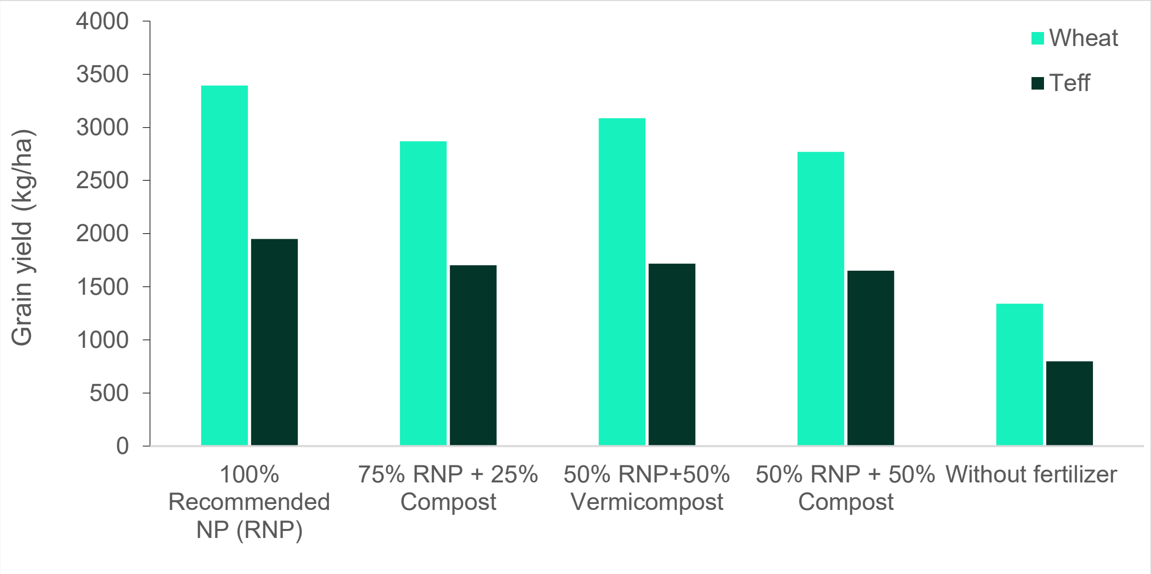

Figure 1. Yields of teff and wheat as influenced by the application of inorganic and organic fertilizers. RNP: Recommended N and P fertilizers

Impacts of ISFM on Soil Properties and Resilience

The integrated application of organic and inorganic fertilizers substantially improved soil chemical properties compared to applying the sole inorganic fertilizer and the control (without any nutrient application). The addition of 50% RNP + 50% compost and 50% RNP + 50% vermicompost increased soil pH by 0.51 and 0.39 units, compared to the control, and by 0.49 and 0.37 units relative to the recommended N and P (RNP) fertilizer rate (Figure 2). Likewise, the integration of organic amendments with inorganic fertilizers considerably improved soil OC, total N, available P, exchangeable cations, and CEC compared to the control and inorganic fertilizer alone. Soils treated with inorganic fertilizer and the control without any nutrients or amendments tested almost the same soil nutrient contents, implying that applying inorganic fertilizer alone without retention of some crop residues depletes the soil OC and nutrient contents. Thus, the ISFM approach is a sustainable solution to enhance soil health and fertility, agricultural productivity, and environmental quality in the long term.

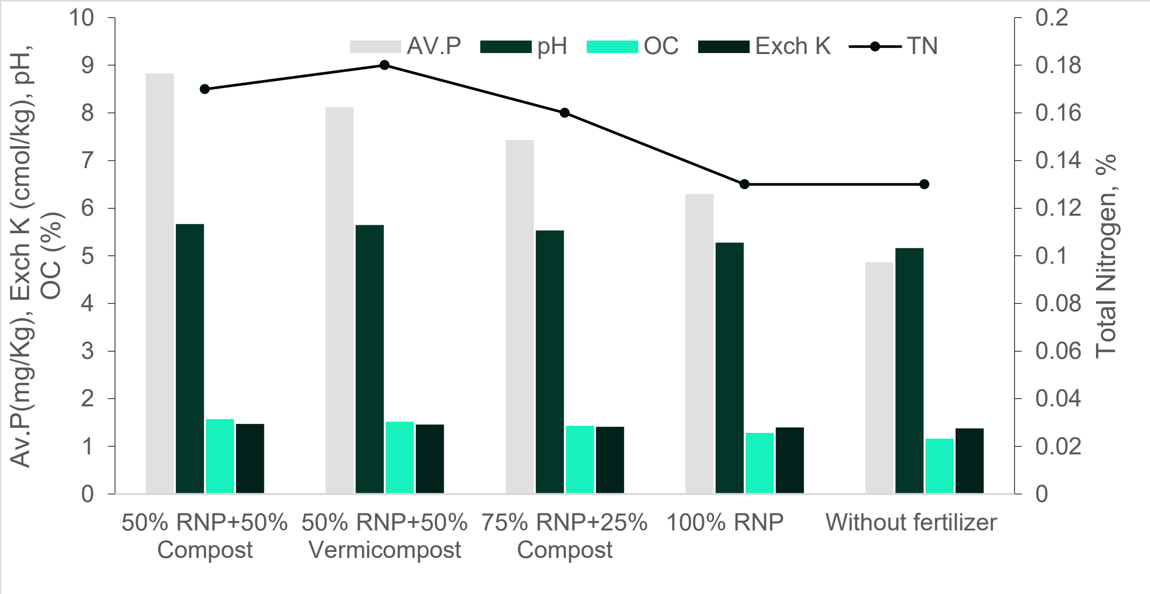

Figure 2. Influence of ISFM practices on soil chemical properties

Economic Benefits of ISFM

The case study demonstrates that the ISFM approach consistently enhanced the economic performance of teff and wheat productivity compared to applying the conventional inorganic fertilizers only. Across the testing locations, ISFM-based practices generated competitive gross benefits (GB), positive net benefits (NB), and favorable marginal net benefits (MNB), underscoring their agronomic and economic superiority over the sole use of inorganic fertilizers or organic amendments only (Table 1). It is concluded that ISFM proved economically competitive for teff and wheat production. In relative terms, wheat displayed greater absolute returns due to higher yield potential, and teff benefited relatively more in terms of input-use efficiency and marginal returns, particularly on resource-constrained farms.

The superior performance of vermicompost-based ISFM could be attributed to its higher nutrient content and faster nutrient release, compared to conventional compost. This synergy enhances nutrient uptake and water retention, resulting in both short-term yield gains and sustained improvements in soil fertility, key contributors to high marginal rate of return (MRR) and benefit-cost ratio (BCR) values. The 50% RNP + 50% compost practice also demonstrated strong economic viability, achieving BCR values comparable to vermicompost, although its MRR was slightly lower (Table 1). However, the ISFM approach remains a low-risk and sustainable option, particularly suitable for resource-constrained farmers to buy or for those with limited access to inorganic fertilizers and families with labor availability for compost preparation.

Table 1. Economic benefits of ISFM practices for teff and wheat production

ISFM practice	GB (USD/ha)	NB (USD/ha)	BCR	MRR (%)	Remark
Teff					
Control	0-1500	0-1500	<1.0	–	Baseline (non-profitable)
100% RNP	4000–4200	2500–3000	1.4–1.8	100–130	High yield but costly
75% RNP+25% compost	3800–4100	2800–3200	1.8–2.2	180–220	Optimal cost–yield balance
50% RNP + 50% compost	3700–4000	2900–3300	1.9–2.4	220–280	Best overall economic performance
50% RNP + 50% VC	3600–3900	2800–3200	1.7–2.1	200–250	Comparable to compost; high efficiency
Wheat					
Control	0-2000	0-2000	<1.0	–	Non-profitable
100% RNP	6000–7200	4000–4800	1.6–1.9	130–160	Highest gross but higher cost
75% RNP + 25% compost	0–1500	4200–5000	1.9–2.3	200–250	High profitability, balanced inputs
50% RNP + 50% compost	4000–4200	4300–5200	2.1–2.4	250–320	Most profitable; optimal integration
50% RNP + 50% VC	3800–4100	4100–5000	1.9–2.2	220–300	Efficient and sustainable

GB: Gross benefits; NB: Net benefits; MNB: Marginal net benefits; MRR: Marginal rate of return; BCR: Benefit-cost ratio; VC: Vermicompost

Conclusion

In conclusion, ISFM proves to meet an optimum agronomic gain and economic benefit, while maintaining the soil stability and resilience against unsustainable and suboptimal farming practices. Based on the availability of organic resources, applying half or a quarter of the recommended rate of organic amendments could compensate 50% or 25% of the recommended rates of inorganic NP fertilizers, and produce comparable yields to those of the recommended inorganic N and P fertilizer rates for teff and wheat production. Therefore, it is critical to translate ISFM practices into the site-specific decision support system for improved soil health and enhanced agricultural productivity. To fulfil this task, potential synergies can be gained by combining technical options with farmers' knowledge, as well as training farmers and development agents on new and innovative soil fertility management approaches.

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The CGIAR Sustainable Science Program forms a part of CGIAR's new Research Portfolio, addressing key challenges in agri-food systems by fostering efficient production of nutritious foods and safeguarding the environment to create fair employment opportunities, as we simultaneously tackle climate change, soil degradation, pests, diseases, and desertification. Its research is being implemented by CGIAR researchers from ICRISAT, in close partnership with NARS and IFDC.

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Resilience, economic benefit, strategies, Ethiopia

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About CGIAR Sustainable Farming Science Program

The CGIAR Sustainable Farming Science Program will address key challenges in agrifood systems by fostering efficient production of nutritious foods and safeguarding the environment to create fair employment opportunities, as we simultaneously tackle climate change, soil degradation, pests, diseases, and desertification.

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