Review of soil fertility status, fertilizer trials, and agronomic opportunities in Southern Ethiopia: focus on Ari, South Omo and Konso zones

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Abstract
Soil fertility decline is one of the major constraints limiting agricultural productivity in South Omo Zone, Southern Ethiopia. Understanding the status of soil nutrients, evaluating fertilizer trial results, and identifying agronomic opportunities are essential for improving crop production and ensuring sustainable land management in the area. This review synthesizes findings from published and unpublished studies conducted in Ari, South Omo, and Konso zones, focusing on soil physicochemical properties, nutrient deficiencies, fertilizer response trials, and management practices. The evidence indicates that soils in the study areas are generally characterized by low to moderate organic matter content, nitrogen deficiency, variable phosphorus availability, and emerging micronutrient limitations in some locations. Fertilizer trials consistently demonstrate significant yield responses to blended fertilizers containing N, P, S, and micronutrients compared to conventional fertilizer recommendations. However, fertilizer use efficiency remains constrained by soil acidity, limited site-specific recommendations, and low adoption of integrated soil fertility management practices. The review highlights key agronomic opportunities, including site-specific nutrient management, integration of organic and inorganic fertilizers, soil acidity management, crop diversification, and improved extension services. Strengthening soil testing capacity and promoting location-specific fertilizer recommendations are critical steps toward enhancing soil productivity and sustainable agricultural development in South Omo Zone.

Keywords: Soil fertility, Fertilizer trials, Agronomic opportunities, Integrated soil fertility management

Introduction

Agriculture remains the backbone of the Ethiopian economy, employing approximately 80–90% of the rural population and contributing nearly half of the national gross domestic product (GDP), as well as a substantial share of export earnings [1, 2]. Agricultural performance is therefore critical for ensuring food security, poverty reduction, and sustainable rural livelihoods. Within this context, soil fertility is a fundamental determinant of crop productivity and long-term agricultural sustainability. Soil fertility refers to the soil's capacity to supply essential plant nutrients while maintaining favorable physical, chemical, and biological conditions to support sustained crop growth and yield [3].

Smallholder farming systems dominate much of southern Ethiopia, including South Omo Zone, Ari, and Konso areas. These systems are characterized by small landholdings, mixed cropping, limited access to improved inputs, and highly variable agro-ecological conditions [4, 5]. Evidence from the region indicates that integrated nutrient management practices, combining organic amendments with mineral fertilizers alongside climate-smart agricultural interventions, can improve soil fertility indicators, crop yields, and soil organic carbon stocks [6-8]. Despite these positive outcomes, soil fertility decline remains a major constraint to sustainable agricultural productivity [9].

Soil fertility degradation in southern Ethiopia is driven by continuous cultivation without adequate nutrient replenishment, removal of crop residues, nutrient mining, soil erosion, soil acidity, and limited access to fertilizers and extension services [10-12]. Phosphorus deficiency and low soil organic matter content are particularly widespread in the region and severely limit crop responsiveness to fertilizers [13, 14]. South Omo Zone, in particular, is dominated by semi-arid to arid lowlands with frequent moisture stress, inherently low soil fertility, and limited access to agricultural inputs [15]. Although field studies have shown that practices such as maize–legume intercropping can enhance soil moisture retention, nutrient availability, and crop productivity [16, 17], comprehensive syntheses integrating soil fertility status, fertilizer trial outcomes, and agronomic opportunities for Ari and Konso areas are scarce.

Despite the reliance on agriculture and recognition of soil fertility as a critical limiting factor, low crop yield responses to fertilizers and ongoing soil degradation persist. For example, the average sorghum yield in South Omo Zone is approximately 2.1 t ha^{-1}, substantially below the attainable yield of 4.5–5.0 t ha^{-1} under improved management [5, 19]. This considerable yield gap underscores the urgent need for targeted soil fertility interventions that are tailored to local agro-ecological and socio-economic conditions.

In response to this challenge, this review was conducted to compile and critically analyze available evidence on soil fertility status, fertilizer trial outcomes, and agronomic practices in South Omo Zone, with particular emphasis on Ari and Konso areas. The review aims to identify key soil fertility constraints, evaluate crop responses to fertilizers, and synthesize context-specific recommendations for sustainable soil fertility management. Specifically, the objectives are to:

- Assess major soil fertility constraints affecting crop productivity in South Omo Zone.
- Evaluate crop responses to fertilizer applications across key agro-ecologies.
- Provide practical, evidence-based recommendations for improving crop productivity through sustainable soil fertility management.

Objectives of the review

- To assess major soil fertility constraints affecting crop productivity in South Omo Zone, with a focus on Ari and Konso areas.
- To evaluate crop responses to fertilizer applications across key agro-ecologies.
- To synthesize existing evidence to provide practical, context-specific recommendations for sustainable soil fertility management.

Material and Methods

Description of the study area

This review encompasses the major agro ecological zones of southern Ethiopia, with specific focus on the Ari, Konso, and South Omo zones. These zones represent diverse altitudinal ranges, climatic conditions, and farming systems, making them suitable for assessing soil fertility status, fertilizer responses, and agronomic opportunities across contrasting environments [1, 15].

The Ari Zone is predominantly located in highland and mid-altitude areas, generally above 1,500 m above sea level. The zone benefits from relatively reliable rainfall, moderate temperatures, and comparatively fertile soils [15, 20]. Agriculture in Ari is largely enset-based, with *Ensete ventricosum* serving as the backbone of local food systems. Enset is commonly intercropped with cereals such as maize, wheat, and teff, as well as legumes including faba bean, alongside perennial fruit crops such as citrus and avocado. These complex, multi-layered farming systems reflect a high level of indigenous knowledge and long-term adaptation to local environmental conditions, contributing to enhanced soil cover, nutrient cycling, and resilience to climatic variability [21, 22].

In contrast, the Konso Zone is internationally recognized for its ancient stone terracing systems, which have been designated as a UNESCO World Heritage cultural landscape. These terraces play a critical role in conserving soil and water in the semi-arid, mid-altitude environment characterized by limited and highly variable rainfall [23]. Agricultural production in Konso relies primarily on drought-tolerant crops, with sorghum forming the foundation of local food security. Sorghum is frequently intercropped with pigeon pea, maize, and cotton, while root and tuber crops such as sweet potato contribute as supplementary food sources. The integration of terracing, intercropping, and organic inputs has historically supported soil fertility maintenance under harsh climatic conditions [24, 25].

The South Omo Zone mainly comprises lowland areas situated below 1,500 m above sea level and is characterized by hot, dry to semi-arid climatic conditions and erratic rainfall patterns [15]. Agricultural systems in this zone are predominantly agropastoral, combining livestock production with the cultivation of crops such as sorghum, sesame, cassava, and forage species. However, frequent moisture stress, low inherent soil fertility, and limited access to agricultural inputs constrain crop productivity and soil fertility management in the zone [26, 27].

Literature search strategy

A systematic and comprehensive literature search was conducted to identify relevant studies undertaken within the geographic boundaries of the Ari, Konso, and South Omo zones. Peer-reviewed journal articles, theses, technical reports, and institutional publications published between 1996 and 2025 were considered. Studies were included if they investigated soil fertility status, fertilizer trials, nutrient management practices, or agronomic interventions relevant to crop production systems in the study areas. Databases such as Web of Science, Scopus, Google Scholar, and national research repositories were consulted, and reference lists of key publications were screened to identify additional relevant sources [1, 3, 6].

Results and Discussion

3.1 Soil fertility status in South Omo Zone

Soil fertility assessments in Ari, Konso, and other districts of South Omo Zone consistently indicate major constraints to crop production. The predominant limitations include strong soil acidity, low soil organic matter (SOM), and widespread nutrient deficiencies, particularly nitrogen (N) and phosphorus (P) [4, 11, 13, 15, 20]. In Ari Zone, soils are strongly acidic (pH 3.3–5.7), with nearly 99% of soils falling into the strongly acidic category, significantly restricting nutrient availability and reducing crop responses to applied fertilizers. In Konso, soil fertility is highly variable due to topography, slope, terracing practices, and soil depth, which influence nutrient distribution and management requirements [4, 15, 20]. Field studies further confirm that nutrient limitations, especially N and P, are key factors constraining yields of maize, sorghum, and haricot bean. The combination of soil acidity, low organic matter, and macronutrient deficiencies underscores the necessity for site-specific soil fertility management strategies (Table 1).

Table 1: Summary of soil fertility indicators (soil pH, organic matter, total nitrogen, available phosphorus, and exchangeable potassium) in Ari, Konso, and South Omo Zone

Location/Zone	Soil pH range	Soil acidity class	Organic Matter (OM)	Key nutrient limitations	Additional observations
Semen Ari District (Ari Zone)	3.29 – 5.68	Strongly acidic (99% of soils)	Low	Low N, Low P	Continuous nutrient mining due to cultivation
Cultivated Land (Ari Zone)	Mostly < 5.5	Acidic	Low OM	N and P deficiencies	Lower fertility compared to grazing/forest land uses
Lowland South Omo (Dasenech, Nyangatom)	Not reported	Moderately to strongly acidic	Low	N and P limitations	Positive yield response to NPSB and higher density confirms nutrient limitation
Konso Woreda	Variable by landscape	Slightly acidic to acidic	Variable	N, P deficiencies	Slope, terracing, and soil depth strongly influence nutrient availability

Source: Compiled from [4,11,13,15,20]

Response to blended fertilizer applications

Field trials conducted in lowland areas of South Omo Zone have demonstrated that blended NPSB fertilizers significantly enhance yield and yield components of major cereal crops, particularly maize and sorghum [7, 11, 12, 15]. Application of site-specific rates of blended fertilizer improved biomass production, panicle characteristics, and grain yield. When fertilizer application was combined with optimized plant density, further yield improvements were achieved under lowland conditions.

Yield responses generally followed a positive quadratic trend, increasing up to an optimum rate of fertilizer application, beyond which gains plateaued or declined, highlighting the importance of determining site-specific optimum fertilizer rates to maximize productivity and input-use efficiency. Similar positive responses were reported for sorghum, where increased plant density improved panicle traits and grain yield under irrigation, despite limitations imposed by low inherent soil fertility [11, 12].

Phosphorus fertilizer trials on haricot bean

Phosphorus application trials on haricot bean (Phaseolus vulgaris L.) across South Omo Zone consistently showed strong positive effects on reproductive growth and yield. Key yield components, including pods per plant, seeds per pod, and 100-seed weight, increased significantly with higher phosphorus rates. The highest grain yield (2.2 t/ha**)** was recorded at 46 kg P ha^{-1}, confirming phosphorus as a major limiting nutrient in low-fertility soils of the region. These results underscore the need for site-specific phosphorus management strategies to improve productivity and fertilizer-use efficiency (Table 3).

Table 2: Summary of blended NPSB fertilizer trial results in South Omo Zone

Crop	Fertilizer treatment (NPSB)	Effect of plant density	Yield response	Key findings
Maize	Blended NPSB fertilizers	Higher plant density increased yield components	Significant increase in grain and biomass yield	Improved harvest index; response limited by soil acidity and low SOM
Sorghum	Blended NPSB fertilizers	Increased density improved panicle traits	Positive grain yield response under irrigation	Yield restricted by low inherent soil fertility
Both Crops	Integrated organic + inorganic fertilizers	Optimized spacing improved performance	Higher nutrient-use efficiency	Soil constraints reduced full fertilizer effectiveness

Source: Compiled from [7,11,12,15]

Table 3: Effect of phosphorus fertilizer rate on haricot bean yield in South Omo Zone

P rate (kg P ha^{-1})	Pods/Plant	Seeds/Pod	100-seed weight (g)	Grain yield (t/ha)
0	14.2	3.1	38.5	1.1
23	18.6	3.5	39.7	1.5
30	20.3	3.8	40.5	1.8
46	22.7	4.1	41.2	2.2

Source: Compiled from [1,5,7,13,15]

Traditional soil fertility management practices

Traditional practices such as intercropping, crop rotation, and farmyard manure (FYM) application remain central to soil fertility maintenance in Ari, Konso, and lowland South Omo districts (Table 5). These practices enhance nutrient cycling, improve soil structure, and stabilize yields under low-input conditions [5, 7, 13, 15].

- **Intercropping:** Maize–legume combinations in Ari improve biological nitrogen fixation, soil moisture use efficiency, and yield stability. In Konso, sorghum intercropped with cowpea or pigeon pea supports soil moisture retention and nutrient use.
- **Crop rotation:** Seasonal rotations between cereals and legumes reduce pest and disease pressure and improve soil nutrient availability.
- **Farmyard manure:** Application improves organic matter and nutrient status, particularly in homestead fields, though limited livestock holdings constrain widespread use.

Table 5: Summary of intercropping, crop rotation, and farmyard manure practices in Ari, Konso, and South Omo Zones

Zone/District	Soil fertility practice	Typical crops/intercrops	Effect on soil fertility and crop productivity	Constraints/Limitations
Ari Zone	Intercropping	Maize + Haricot bean, Maize + Pigeon pea	Improves nitrogen fixation, soil moisture use, and yield stability	Requires knowledge of suitable crop combinations
Ari Zone	Crop rotation	Cereals ↔ Legumes	Reduces pest and disease pressure; enhances nutrient cycling	Limited by land availability
Konso Woreda	Intercropping	Sorghum + Cowpea, Sorghum + Pigeon pea	Conserves soil moisture, reduces erosion, improves nutrient use	Labor-intensive; slope variation affects implementation
Konso Woreda	Farmyard manure application	Sorghum, legumes	Adds organic matter, enhances nutrient availability	Limited quantity due to small livestock holdings
South Omo (Dasenech & Nyangatom)	Rotational cropping	Maize, Sorghum, Legumes	Restores soil fertility partially; reduces continuous cropping effects	Moisture stress limits crop diversity
South Omo	Farmyard manure application	Maize, Sorghum	Improves organic matter and nutrient status in homestead fields	Limited availability; competing household uses

Source: Compiled from [5, 7, 13, 15]

Agronomic opportunities for enhancing productivity

Integrating traditional practices with modern interventions presents significant opportunities for sustainable crop production. Key measures include:

- **Soil pH correction:** Liming acidic soils enhances fertilizer efficiency and nutrient availability [1].
- **Site-specific fertilizer recommendations:** Optimizing rates based on soil variability rather than blanket applications [1].
- **Improved agronomic practices:** Optimizing plant spacing, planting density, intercropping, and moisture conservation, particularly in terraced landscapes in Konso [10].

Table 6: Agronomic opportunities for crop production in Ari Zone

Opportunity	Description	Reference
Soil pH Correction	Liming acidic soils in Ari Zone improves fertilizer efficiency and nutrient availability.	[1]
Site-Specific Fertilizer Recommendations	Tailoring fertilizer application rates based on soil fertility variability, rather than using blanket recommendations.	[1]
Improved Agronomic Practices	Optimizing plant spacing, planting density, intercropping, and moisture conservation practices to enhance crop productivity, especially in terraced fields in Konso.	[10]

Source: Compiled from studies on agronomic practices in South Omo Zone, including [5,7, 15].

Conclusion

This review aimed to assess soil fertility constraints, evaluate fertilizer response patterns, and synthesize existing evidence to guide sustainable soil fertility management in Ari, Konso, and South Omo Zones of southern Ethiopia. The evidence consistently shows that high soil acidity, low soil organic matter, and deficiencies of essential nutrients particularly nitrogen and phosphorus are the dominant constraints to agricultural productivity in the region [1]. Findings from fertilizer trials on major crops such as maize, sorghum, and haricot bean confirm that the application of blended NPSB fertilizers and phosphorus significantly improves grain yield and yield components [11, 12]. These results clearly demonstrate that nutrient limitation, rather than genetic potential alone, is a primary driver of low productivity. However, the magnitude of crop response varies across zones due to differences in soil characteristics, landscape features, and management practices. In the Ari Zone, soil acidity reduces nutrient availability and limits fertilizer use efficiency, indicating the necessity of integrated soil amendment strategies. In Konso, slope-related constraints, terracing systems, and limited site-specific research hinder optimal nutrient recommendations [10, 15]. Across the reviewed studies, integrated soil fertility management—including balanced fertilization, incorporation of organic amendments, liming to correct soil pH, and improved agronomic practices-emerges as the most consistent and sustainable strategy for enhancing productivity while maintaining soil health [14]. In conclusion, improving soil fertility in southern Ethiopia requires moving beyond isolated fertilizer applications toward integrated, evidence-based, and location-specific management strategies. Addressing soil acidity, nutrient deficiencies, and research gaps will be essential to achieving sustainable crop productivity and long-term soil health in the region.

Recommendations

Based on the reviewed evidence, the following priority actions are recommended:

a) **Promote Integrated Soil Fertility Management (ISFM):** Combine balanced mineral fertilizers (e.g., NPSB and phosphorus) with organic amendments to improve nutrient use efficiency and soil organic matter status, as supported by multiple crop response trials [11, 12, 14].

b) **Address soil acidity through liming programs:** In highly acidic areas such as Ari Zone, scaling up liming interventions is essential to enhance fertilizer effectiveness and improve nutrient availability.

c) **Strengthen site-specific fertility research:** Particularly in Konso Zone, long-term, location-specific soil fertility assessments and fertilizer trials are needed to generate context-driven nutrient recommendations.
d) **Enhance farmer-oriented extension services:** Translate research findings into practical, location-specific guidelines that consider landscape variability, cropping systems, and resource availability.
e) **Encourage long-term soil monitoring:** Sustainable productivity requires continuous evaluation of soil chemical and biological properties to prevent degradation and ensure resilience.

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