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Review Article

Integrated Nutrient Management: A Review on Effects of Combined Organic and Inorganic Fertilizers on Cabbage (*Brassica oleracea var. capitata* Linn.) Production in Ethiopia

Usman Mohammed Ali

Department of Plant Science, Wollega University, Shambu, Ethiopia

Abstract

Cabbage (Brassica oleracea var. capitata Linn.) is a globally significant vegetable crop with high nutritional and economic value. In Ethiopia, its production faces challenges such as soil fertility depletion, high input costs, and suboptimal fertilizer use. This review examines the effects of integrated nutrient management (INM) on cabbage production in Ethiopia by synthesizing regional studies. The review analysis demonstrates that combining organic (poultry manure at 10-15 tons/ha) and inorganic fertilizers (NPK at 100 kg/ha) optimizes yield, head weight (940.4g vs. 374.4g for the Copenhagen variety), and nutrient uptake while enhancing soil health. Key findings reveal that integrated applications improve head diameter by 28% compared to control groups. A balanced ratio of 70% organic and 30% inorganic fertilizers is recommended to harmonize immediate productivity gains with long-term sustainability. Despite these benefits, barriers persist, including limited farmer knowledge, inadequate policy frameworks, and a lack of region-specific INM strategies. Future efforts must prioritize farmer education, policy reforms, and targeted research to bridge yield gaps and promote food security. Promoting INM practices such as poultry manure + NPK or compost + urea blends can enhance food security and mitigate the environmental impacts of cabbage production in Ethiopia.

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*Corresponding Author:
Usman Mohammed Ali
E-mail:
ausmanmohammed77@gmail.com

INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata* Linn.) is a globally important vegetable crop belonging to the family *Brassicaceae* (*Cruciferae*) and the genus *Brassica*. With a diploid chromosome number of 2n=2x=18, it is widely consumed both fresh and in processed forms across the world. The crop is believed to have originated in Western Europe and the northern Mediterranean coastal regions, evolving from its wild, non-heading progenitor, Colewort (*Brassica oleracea* var. *sylvestris*) (Parkash et al., 2023).

Cabbage is cultivated across five continents and in over ninety nations (Gelaye, 2024), holds a prominent position in worldwide vegetable production, ranking among the top twenty according to the Food and Agriculture Organization (FAO, 2025). Cabbage is an important component of both human and animal diets, valued for its considerable nutritional content (Asomah et al., 2021),

Beyond its significance as a food and fodder crop, cabbage also holds applications in pharmaceutical manufacturing. Consumption of cabbage is associated with long-term health advantages, notably its potential role in cancer prevention. Research by Connolly et al. (2021) indicated that the consistent intake of glucosinolates present in cabbage may lower the probability of cancer initiation and the proliferation of cancerous cells. In Ethiopia, however, cabbage production currently encounters substantial challenges, including elevated input expenses, declining soil fertility, and adverse climatic conditions.

The growth and yield of cabbage are significantly modulated by both organic and inorganic nutrient inputs. While the application of inorganic fertilizers in crop production raises health concerns due to potential residual effects, organic fertilizers generally do not present such issues. Conversely, inorganic fertilizers are recognized for their capacity to enhance soil productivity and fertility, alongside improving crop quality and yield potential (Asomah et al., 2021).

Fertilizer application is a critical factor in accelerating plant growth by providing essential macro- and micronutrients that enhance soil nutrient availability (Asadu et al., 2024). Soil fertility and overall quality are intrinsically linked to the biological activity within the soil, which is vital for promoting adequate soil aeration and subsequently enhancing crop productivity. Indeed, soil microorganisms are indispensable components of the soil ecosystem, performing multiple critical functions such as nutrient cycling, soil organic matter decomposition, pathogen control, and plant growth promotion. However, the inappropriate selection of fertilizer types and the inaccurate determination of application rates represent significant limitations to achieving optimal crop performance even under favorable environmental conditions. Consequently, employing appropriate fertilizer rates, considering the vital role of soil biology, is essential to meet consumer demands for agricultural produce (Wang et al., 2025).

A significant challenge for many farmers in Ethiopia and across numerous developing nations is the limited technical expertise in selecting and applying suitable fertilizers for their crops. Notably, the synergistic effects of integrating organic and inorganic fertilizers on the growth and yield characteristics of cabbage have not received adequate research attention. The incorporation of organic fertilizers is well-documented to substantially enhance soil water retention, improve nutrient availability, regulate the carbon-to-nitrogen ratio, and elevate both macro- and micronutrient levels, ultimately leading to improvements in crop yield, size, flavor, aroma, and overall quality (Timsina, 2018).

Notwithstanding the considerable advantages of organic fertilization, crop yields under such regimes have been reported to be approximately 20% lower compared to those achieved with inorganic fertilizers. These yield considerations underscore the necessity for adopting integrated approaches combining organic and inorganic nutrient sources. Integrated nutrient management has demonstrated its efficacy in maintaining crop yields, enhancing the physicochemical properties of soils, and improving nutrient uptake by plants. While organic fertilizers are crucial for long-term agricultural sustainability by improving soil fertility, the benefits of synthetic inorganic fertilizers, though often immediate, can be accompanied by detrimental long-term consequences, including soil toxicity, acidification, and a decline in overall soil fertility. Thus, this review was undertaken to critically examine the effects of both organic and inorganic fertilizers on the growth and yield of head cabbage (Paramesh et al., 2023).

This review serves as a critical resource for various stakeholders:

Farmers: This review report provides insights into effective fertilizer applications that can increase crop yield.

Researchers: This review can guide future studies on integrated nutrient management strategies.

Policymakers: This review offers evidence-based recommendations for developing agricultural policies that promote sustainable practices in fertilizer use.

The review methodology involves a comprehensive literature analysis focusing on the following:

The historical context and importance of cabbage cultivation globally and in Ethiopia.

This is a detailed review of existing studies on the effects of both organic and inorganic fertilizers on cabbage growth and yield.

LITERATURE REVIEW

Origin, Distribution, and Botany of Cabbage

Brassica oleracea is a cultivated species of significant agricultural importance that exhibits remarkable morphological diversity, giving rise to various vegetables such as cabbage, broccoli, cauliflower, kale, kohlrabi, and Brussels sprouts. The extraordinary diversity observed within this single species renders *B. oleracea* an excellent model system for elucidating the impact of artificial selection on plant development and morphology (Mabry et al., 2021).

Wild cabbage serves as the progenitor for this diverse array of cole crops, all resulting from human-mediated breeding practices. The genus *Brassica*, to which cabbage belongs, encompasses approximately 100 species, with a majority originating from the Mediterranean region. The cultivated head cabbage (*Brassica oleracea* var. *capitata*) is hypothesized to have originated in the Eastern Mediterranean region, with its domestication tracing back to a non-heading wild ancestor, 'Cole wort' (*Brassica oleracea* var. *sylvestris*), which still exists in regions including Denmark, northwestern France, and eastern England. This ancient vegetable crop boasts a cultivation history extending beyond recorded human history, with evidence indicating its importance as early as ancient Greece, where it was considered a significant vegetable of divine origin. Ancient Greek cultivation dates back to at least 600 BC, and its characteristics were documented by Theophrastus around 350 BC (Maggioni et al., 2010).

Historical records indicate that ancient Romans and Saxons cultivated and introduced softer-headed cabbage varieties to the British Isles, while the development of hard-headed types is documented around the 9th century. Head cabbage cultivation was established in Germany by the 12th century and in England by the 14th century. Presently, head cabbage is widely cultivated in most temperate regions and has gained significant popularity in tropical Africa (Mabry et al., 2021).

Cabbage production in Ethiopia and Africa is dominated by several key varieties, each with distinct characteristics and cultivation advantages. The *Copenhagen* variety is widely grown in Ethiopia's central highlands due to its adaptability and strong market demand, while *Early Drumhead* is favored for its shorter maturity period. *Red cabbage*, distinguished by its anthocyanin-rich purple leaves, offers a unique nutrient profile compared to *white cabbage*, which remains the most common type with its firm, round head and green outer leaves (Gelaye, 2024). Nutrient absorption in cabbage is influenced by fertilizer type: organic fertilizers (e.g., manure, compost) enhance soil structure and microbial activity for gradual nutrient release, whereas inorganic fertilizers provide immediate nitrogen, phosphorus, and potassium (Liu et al., 2024). Research highlights that integrated nutrient management (combining both types) optimizes yield and nutrient content, with red cabbage potentially exhibiting different uptake efficiencies due to its anthocyanin content.

Cabbage is a heavy feeder, particularly requiring nitrogen and potassium, with optimal nutrient ratios varying by soil, climate, and variety. Studies demonstrate that organic fertilizers improve long-term soil health, while inorganic fertilizers deliver rapid growth boosts. For instance, nitrogen and sulfur applications significantly enhance yield parameters. Tailoring fertilizer strategies to specific varieties, such as adjusting nitrogen levels for red cabbage's anthocyanin synthesis, can maximize productivity

(Kavaliauskaitė et al., 2023). Below, a comparison of red and white cabbage highlights their differences in nutrient profiles and cultivation responses (Table 1).

Table 1

Comparison of Red and White Cabbage

Feature	Red Cabbage	White Cabbage
Color/Pigmentation	Deep purple/red (anthocyanins)	Pale green to white
Nutrient Profile	Higher antioxidants (anthocyanins, vitamin C)	Rich in vitamin K, fiber
Soil Preference	Thrives in well-drained, fertile soils	Adaptable to a wider soil range
Fertilizer Response	May require higher sulfur for pigment	Responds strongly to nitrogen
Yield Potential	Slightly lower (prioritizes quality)	Higher yield in optimal conditions
Market Demand	Niche markets (health-conscious buyers)	Broad commercial demand

World Cabbage Production and Its Nutritional and Health Significance

Cabbage, a cool-season vegetable, is widely cultivated throughout most temperate regions worldwide. Global annual cabbage production is substantial, estimated at approximately 73,828,504.77 million metric tons, with an average productivity of around 29.23 tons per hectare (FAO, 2025). Regional production trends indicate that Asia accounts for the largest share (77.4%), followed by Europe (13.5%), Africa (5.5%), America (2.9%), and Oceania (0.2%) (Figure 1). The top ten global producers of cabbage include China, India, the Russian Federation, the Republic of Korea, Ukraine, Japan, Indonesia, Vietnam, the United States of America, and Poland (FAO, 2025).

Head cabbage has gained increasing importance in tropical and subtropical regions in recent decades, with Africa estimated to have around 100,000 hectares under cultivation (Eastern Africa, including Kenya, Uganda, and Tanzania, accounts for a significant portion, with approximately 40,000 hectares of white-headed cabbage, while Ethiopia has around 4,000 hectares) (Aktaş & Bakkalbaşı, 2016). Notably, vegetable cultivation, including cabbage, can occur year-round given sufficient soil moisture.

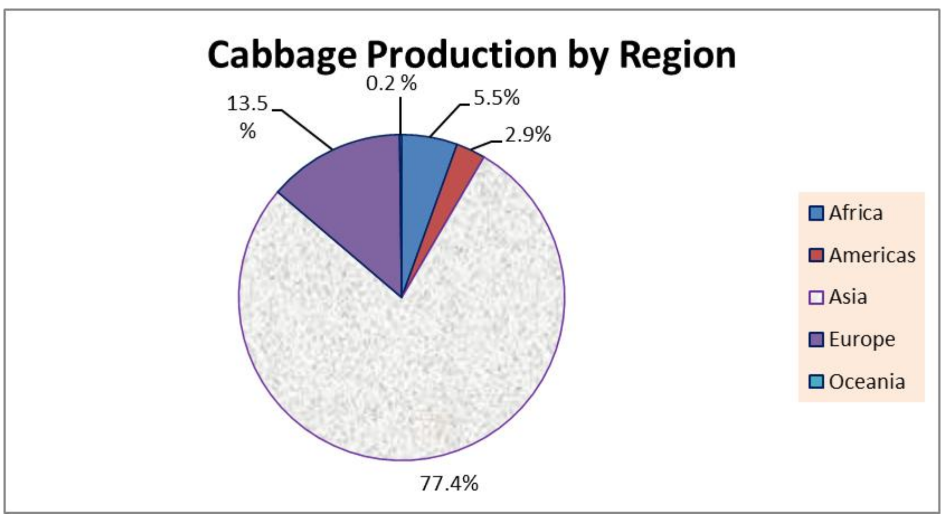

Figure 1. *Regional share of global cabbage production. (Source: Compiled by the author based on FAO, 2025).*

Recognized by the Food and Agriculture Organization of the United Nations as one of the top twenty vegetables consumed worldwide, cabbage is versatile in its culinary applications. It is commonly consumed cooked (boiled or stir-fried) or raw, as a key ingredient in coleslaw and mixed salads. Furthermore, cabbage is utilized in the production of processed foods such as pickles.

Nutritional analysis confirms cabbage as a significant source of essential vitamins, proteins, carbohydrates, and crucial minerals. A 100-gram edible serving provides substantial quantities of vitamin A (2000 IU), thiamine (0.06 mg), riboflavin (0.03 mg), protein (1.8 g), lipids (0.1 g), carbohydrates (4.6 g), and a notably high concentration of vitamin C (124 mg) (Bhardwaj, 2024). Additionally, this serving contributes essential minerals, including phosphorus (44 mg), potassium (114 mg), calcium (39 mg), sodium (14.1 mg), and iron (0.8 mg) (Bhardwaj et al., 2024).

The presence of significant bioactive compounds in *Brassica oleracea* var. *capitata* contributes to its diverse effects on glucose homeostasis. Research suggests its potential to mitigate organ damage associated with type 2 diabetes mellitus (T2DM), particularly in the liver and kidneys (Uuh-Narvaez & Segura-Campos, 2021). Moreover, cabbage's capacity to alleviate oxidative stress and counteract obesity indicates its potential as a prophylactic agent against T2DM. Consequently, this crop holds value as a component of nutritional interventions and functional food formulations aimed at supporting T2DM prevention and management. Beyond its glucose-regulating properties, cabbage also exhibits acid-neutralizing, cooling, digestive, and appetite-stimulant effects, potentially offering benefits for individuals with diabetes.

Glucosinolates, the primary organo-sulfur compounds found in cruciferous vegetables such as cauliflower, cabbage, broccoli, Brussels sprouts, kale, radish, and turnips, have been linked to health benefits. Epidemiological studies suggest that diets rich in these vegetables may reduce the risk of certain cancers, including lung and colon cancer. The anti-carcinogenic properties of glucosinolates are attributed to their complex mechanisms of action, involving effects on Nrf2 signaling, modulation of genetic polymorphisms, anti-inflammatory activities, inhibition of histone deacetylase activity, and influence on estrogen metabolism (Connolly et al., 2021).

Head Cabbage Production in Ethiopia

Head cabbage (*Brassica oleracea* var. capitata) is an important vegetable crop in Ethiopia, cultivated mainly in the mid-altitude and highland agroecological zones, with smallholder farmers forming the backbone of its production (Ejigu, 2024). The crop is grown predominantly during the rainy season, though some commercial farms use irrigation for year-round supply. Nationally, the area dedicated to cabbage cultivation has expanded in recent years. In 2019/20, approximately 38,000 hectares were under cabbage, producing nearly 395,000 tons (3,950,000 quintals) across both rain-fed and irrigated conditions (CSA, 2020). By 2022, this area increased to about 50,000 hectares, with production rising to 482,000 tons (4,820,000 quintals), indicating a steady growth in both area and output at an average yield of around 9.7 tons per hectare (97 quintals/ha) (IndexBox, 2025).

Regional Production Patterns

The Central Statistical Agency (CSA, 2020) survey for 2019/20 provides a regional breakdown of head cabbage cultivation. In Tigray, 2,710 hectares were planted, yielding 8,825 quintals, which translates to a yield of about 3.26 quintals per hectare, a figure likely reflecting underreporting of production or localized constraints. The Amhara region reported 3,720 hectares under cabbage, though production quantities were not explicitly stated in the CSA summary tables. Other regions, such as Oromia, SNNP, and Benishangul Gumuz, did not report significant cabbage production in the 2019/20 survey, or the data were not available, suggesting that head cabbage cultivation is more concentrated in specific highland areas, especially in the north and central parts of the country (CSA, 2020). More recent literature and market analyses indicate that Oromia and Amhara have become leading regions in cabbage production, with notable expansion in the Bale zone (Oromia) and West Amhara, driven by both smallholder and commercial farms (Ejigu, 2024).

Trends and Comparative Analysis

Cabbage production in Ethiopia has demonstrated a positive growth trajectory from 2019 to 2022, with a notable increase in both harvested area and total output (ESS & World Bank, 2023). During this period, the harvested area expanded from approximately 38,000 ha to 50,000 ha, while production rose from 395,000 to 482,000 tons. This expansion corresponds to an average annual growth rate of about 7% for area and 6.9% for output. Despite this promising trend, national average yields, ranging from 9.7 to 10.4 tons/ha, remain substantially lower than global benchmarks (Index Box, 2025). This discrepancy is attributed to several key factors, including the limited adoption of improved varieties, suboptimal agronomic practices, and significant post-harvest losses. A considerable regional yield gap is also evident, with experimental yields under optimal management at research stations reaching 94-118 tons/ha, a stark contrast to the lower yields typically obtained in farmer fields. Cabbage cultivation is most prominent in highland regions such as Amhara, Oromia (notably the Bale zone), and Tigray. The disparity between potential and actual yields underscores a critical need for enhanced agronomic practices, broader access to high-yielding varieties, and improved post-harvest management strategies to fully realize the crop's potential and boost productivity for Ethiopian farmers (Index Box, 2025).

Advantages and Disadvantages of Organic Fertilizers

Advantages of organic fertilizers

Organic fertilizers enhance soil structure by contributing humus, a stable form of organic matter characterized by its high cation and anion exchange capacity. This property enables the soil to retain both positively charged (cations) and negatively charged (anions) nutrient ions, facilitating their availability for plant uptake through ion exchange processes. The humus component introduced by organic fertilizers exhibits a high water-holding capacity, effectively adsorbing substantial amounts of moisture and thereby enhancing water availability for plants, particularly during periods of drought stress. This water retention characteristic, coupled with the enhanced nutrient retention provided by humus, is especially critical for sandy soils, which are inherently limited in their capacity to retain both water and nutrients (Khan et al., 2024).

Additionally, humus, a key component of organically fertilized soils, acts as a significant buffer system, effectively regulating the equilibrium between acidity and alkalinity in the soil solution, thereby stabilizing soil pH (Jeon et al., 2023). The incorporation of organic fertilizers enhances soil organic matter content, leading to improved soil structure and workability, often referred to as soil tilth, which facilitates plowing in both sandy and clay soils (Ghimirey et al., 2025).

Clay soils, characterized by limited macropore space, can impede the transport of essential resources such as water and oxygen to plant roots, potentially causing root suffocation and plant stress. This directly affects plant health and indirectly increases susceptibility to diseases and pests. Consequently, the application of organic fertilizers plays a crucial role in improving the structure of clay soils by fostering the formation of macropores, which enhances both aeration for root respiration and water drainage, thereby creating conditions conducive to optimal plant growth (Liu et al., 2024).

Disadvantages of Organic Fertilizers

Despite their benefits, organic fertilizers present certain disadvantages. Nutrient release is not immediate, as it relies on the gradual decomposition by soil microorganisms. Precise nutrient content and release rates are often uncertain, making it challenging for farmers to determine exact nutrient availability. Nutrients from organic amendments are released slowly because soil microorganisms break them down, making them available to plants later than inorganic fertilizers do. The rate at which these nutrients become accessible to plants is influenced by several interacting factors, including the efficiency of nutrient uptake by the specific crop, the extent of nitrogen losses through processes like volatilization or leaching, the synchrony between nutrient release and the crop's growth stages (determined by planting time), and prevailing climatic conditions, notably temperature and rainfall patterns at the cultivation site (Li et al., 2024).

The other disadvantage is that organic fertilizers can be costly and bulky, particularly when transportation distances are significant. Correcting nutrient deficiencies can be difficult due to the unknown quantities and release dynamics of nutrients. Improper application can lead to nitrate accumulation in groundwater and crops. Inadequately processed organic materials may harbor plant or animal pathogens harmful to humans or plants. Additionally, compost derived from municipal waste or sewage may contain toxic heavy metals like lead, cadmium, and arsenic, necessitating proper treatment to avoid food contamination and reduced crop quality (Liu et al., 2024).

Nutrient Content of Organic Fertilizers

The nutrient composition of organic fertilizers exhibits variability due to the diverse nature of their raw material sources. Generally, bovine or kraal manure tends to have the lowest nutrient concentrations, while poultry manure typically presents the highest. Fresh poultry manure can contain two to three times more nitrogen compared to kraal manure or compost. Notably, the nutrient profile of manure is significantly influenced by the dietary quality of the livestock. Diets richer in protein lead to manure with higher nitrogen content, suggesting a management strategy of feeding animals protein-rich rather than carbohydrate-rich feed to enhance manure nitrogen. Similarly, increased phosphorus and potassium content in animal feed directly translates to higher concentrations of these elements in the resulting organic fertilizer (Sindhu et al., 2020).

The nutrient composition of organic fertilizers is further influenced by factors such as age and exposure to atmospheric conditions. Prolonged exposure and subsequent drying can lead to significant nitrogen losses through volatilization. Additionally, potassium content may be reduced due to leaching by rainwater. Given the multitude of factors affecting their chemical composition, it is advisable to utilize organic fertilizers relatively soon after their production to maximize nutrient retention (Mahmud et al., 2021).

Effects of Organic and Inorganic Fertilizers on Head Cabbage

Organic fertilizers, characterized by their defined chemical composition and substantial nutritional content, serve as a source of essential nutrients for plant growth. These fertilizers are primarily produced through the composting of animal manure, human excreta, or plant-based materials (such as straw and garden waste) via microbial fermentation under thermophilic conditions. While organic fertilizers contain mineral nutrients bound within complex organic molecules, their nutrient concentrations are generally lower compared to their inorganic counterparts. However, their application is known to improve soil structure, supply a diverse array of plant nutrients, and introduce beneficial microorganisms into the soil ecosystem. Consequently, owing to their positive responses on soil health and crop productivity, organic fertilizers are extensively utilized in various agricultural systems. In contrast to inorganic fertilizers, organic amendments typically exhibit a more prolonged residual effect on soil fertility (Wang et al., 2025).

Inorganic fertilizers are formulated with specific chemical compounds to deliver essential nutrients rapidly, even under suboptimal environmental conditions, such as during autumn and spring. Unlike organic fertilizers, their nutrient availability is not contingent on microbial activity. Consequently, inorganic fertilizers are required in comparatively smaller quantities and offer advantages in storage and application efficiency. However, they do not contribute humus to the soil, which can result in a diminished capacity for nutrient and water retention compared to soils amended with organic matter. This lower water-holding capacity, coupled with the high solubility of inorganic fertilizers, can lead to accelerated nutrient leaching, particularly of nitrogen, from the soil profile (Liu et al., 2020).

Given its high nutrient demand, cabbage production typically necessitates supplementary fertilization through organic amendments like manure or compost, as well as inorganic fertilizers. Optimal fertilizer application rates should be determined by site-specific soil fertility assessments. However, in Ethiopia, such precision agriculture practices are not widely adopted, with organic fertilizer application often based on generalized recommendations irrespective of soil type. According to guidelines by ARARI (2005), recommended nitrogen and phosphorus application rates for cabbage production in Ethiopia vary based on soil fertility levels. For fertile soils, the recommendation is approximately 150 kg NPSB and 100 kg urea per hectare, while non-fertile soils require around 200 kg NPSB and 100 kg urea per hectare. The standard practice involves applying the entire NPSB and half of the urea at planting, with the remaining half of the urea applied as a top dressing approximately 30 days post-transplanting (ARARI, 2005).

In Ethiopia, conventional cabbage fertilization follows blanket recommendations of 242 kg/ha NPS and 79 kg/ha urea, applied through split doses with half the urea typically applied 30 days post-transplanting (Gelaye, 2024). While these standardized rates provide a baseline, optimal application varies significantly with soil fertility, ranging from 150 kg NPSB + 100 kg urea in fertile soils to 200 kg NPSB + 100 kg urea in nutrient-deficient areas. Farmers frequently supplement with organic amendments (8-12 tons/ha manure or compost) pre-transplanting, though excessive nitrogen application during head formation risks yield-reducing splitting. Critical knowledge gaps persist regarding nitrogen optimization across Ethiopia's diverse agroecologies, particularly in determining region-specific thresholds that balance yield maximization with quality preservation while minimizing nutrient leaching from inorganic sources (Gelaye, 2024). This accentuates the need for targeted research to refine fertilizer recommendations through soil-specific nutrient management strategies that integrate organic and inorganic sources.

Effects of Organic and Inorganic Fertilizers on Growth Promoters and Yield Components of Cabbage

Influence of Organic Fertilizers on Growth and Yield

Organic fertilizers, such as farmyard manure (FYM), compost, and poultry manure, play a crucial role in promoting cabbage growth by enhancing the physical, chemical, and biological properties of the soil. Their characteristic slow nutrient release pattern ensures a continuous supply of essential macro- and micronutrients. This sustained nutrient availability fosters balanced vegetative growth and significantly improves root development, which are vital for a healthy and productive cabbage crop (Liu et al., 2024).

These organic amendments notably improve the soil ecosystem, leading to more vigorous cabbage growth. They achieve this by increasing soil microbial biomass and enzymatic activity, both of which are critical for the mineralization of nutrients and their subsequent uptake by plants. The resulting improved nutrient access leads to a higher chlorophyll content, larger leaf areas, and enhanced photosynthetic efficiency, all of which contribute to the development of stronger and more robust cabbage plants (Wichaphian et al., 2025).

When it comes to yield, organic fertilizers consistently deliver impressive results. They improve nutrient availability and water retention in the soil, which translates into larger head diameters, increased head weights, and a greater overall marketable yield (Khan et al., 2024). For instance, studies have shown that applying poultry manure at rates of 10 to 15 tons per hectare can increase cabbage head weight by as much as 25% when compared to plots that don't receive fertilizer (Paramesh et al., 2023). Researchers have explored various application rates for organic fertilizers, with common recommendations ranging from 10 to 20 tons per hectare for farmyard manure (FYM) and 5 to 15 tons per hectare for poultry manure (Ghimirey et al., 2025). Generally, increasing these doses incrementally has been observed to correlate with further improvements in yield parameters.

Effects of Inorganic Fertilizers on Cabbage Growth and Yield

Inorganic fertilizers such as urea and NPK blends play a pivotal role in cabbage production by supplying nutrients in forms that are immediately available to plants. These fertilizers are particularly valued for their ability to meet the high nutrient demands of cabbage during its rapid growth stages, ensuring vigorous development and uniform crop stands within a relatively short growing period (Gelaye, 2024).

Regarding growth promoters, nitrogen from urea is essential for stimulating leaf expansion and enhancing chlorophyll synthesis, which directly influences the plant's photosynthetic capacity. Phosphorus, commonly supplied through NPSB, is vital for robust root development and efficient energy transfer within the plant system. Potassium, another key nutrient in NPK blends, contributes to effective water regulation and strengthens the plant's resistance to diseases, collectively supporting optimal vegetative and reproductive growth (Ghimire et al., 2023).

The impact of inorganic fertilizers on cabbage yield and its components is well documented. Research indicates that applying NPK fertilizers at rates of 100–200 kg/ha can significantly increase head weight, often resulting in yields that are double those of unfertilized controls. With optimal inorganic fertilizer management, cabbage head weights ranging from 800 to 900 grams have been consistently reported, reflecting substantial improvements in both marketable yield and overall crop quality (Asomah et al., 2021).

Integrated Nutrient Management (INM)

Combining organic and inorganic fertilizers through Integrated Nutrient Management (INM) optimizes nutrient availability while enhancing soil health and cabbage productivity. This approach leverages the complementary benefits of both nutrient sources: organic amendments improve soil structure and microbial activity, while inorganic fertilizers provide readily available nutrients. As a result, INM systems consistently outperform sole applications of either fertilizer type in terms of crop growth, yield, and long-term soil sustainability (Paramesh et al., 2023).

INM fosters robust cabbage growth by enhancing soil microbial activity and nutrient cycling. The synergistic interaction between organic matter and mineral fertilizers promotes root development, increases nutrient uptake efficiency, and improves plant resilience to abiotic stresses. For instance, the gradual release of nutrients from organic sources sustains plant demand, while inorganic fertilizers address immediate nutrient deficiencies. This dual mechanism ensures balanced vegetative growth and reduces nutrient losses (Sande et al., 2024).

Studies demonstrate that INM significantly boosts cabbage yield and quality. For example, combining 10 tons/ha of poultry manure with 100 kg/ha of NPK increased head diameter by 28% and head weight by over 30% compared to inorganic-only treatments. These improvements are attributed to better nutrient synchrony, improved soil moisture retention, and enhanced physiological efficiency. Such integrated systems also reduce dependency on chemical inputs, aligning with sustainable agricultural goals (Gelaye, 2024).

Effective INM typically involves 10–15 tons/ha of organic manure (e.g., farmyard or poultry manure) combined with 75–150 kg/ha of inorganic fertilizers, adjusted for soil fertility and crop requirements. Tailoring these ratios based on soil testing ensures optimal nutrient use efficiency while minimizing environmental risks. Farmers adopting INM report not only higher yields but also improved soil organic carbon and long-term field productivity (Ghimire et al., 2023).

Table 2

Comparative effects of organic, inorganic, and integrated fertilizers on cabbage growth and yield components

Fertilizer Type	Applied Dose	Head Weight (g)	Head diameter (cm)	Yield (t/ha)	Soil Health Impact
Control (No fertilizer)	-	350–400	9–11	15–18	Neutral
Organic (Poultry manure)	10–15 tons/ha	600–700	14–16	22–26	Improves soil structure & biology
Inorganic (NPK)	100–150 kg/ha	800–900	17–19	30–35	Immediate nutrient supply; risk of soil acidification if overused
Integrated (Poultry+NPK)	10 tons/ha + 100 kg/ha NPK	900–950	20–22	35–40	Enhances soil fertility and sustainability

*(**Source:** Asomah et al., 2021; Ghimire et al., 2023' Gelaye, 2024; Ghimirey et al., 2025).*

The above detailed effects of organic and inorganic fertilizers on cabbage growth and yield components reveal that while inorganic fertilizers provide rapid and high yield gains, organic fertilizers contribute to long-term soil health and sustainability. Integrated nutrient management, combining both fertilizer types at appropriate doses, offers the most balanced and effective strategy for maximizing cabbage growth promoters, yield, and quality under Ethiopian conditions (Table 2).

Factors affecting the effectiveness of organic fertilizers

The efficacy of high-quality organic fertilizers is contingent upon the synergistic interaction with several key environmental and management factors, including water availability, inherent soil characteristics (type, depth, pH, slope, and temperature), and the synchronicity of cultural practices. Additionally, the temporal aspect of organic fertilizer application is critical, as its effectiveness is modulated by ensuring the release and availability of appropriate nutrients to the soil at specific crop growth stages (Xing et al., 2024).

Timing of Organic Fertilizer Application

Strategic timing of organic fertilizer application is crucial for optimizing plant nutrient availability. In warmer climates, maintaining soil humus levels can be challenging due to accelerated decomposition rates and the subsequent release of carbon into the atmosphere. Prior to application, organic fertilizers should undergo analysis to ascertain the concentration of essential nutrients and the presence of any potentially toxic elements.

Nutrient application rates should be carefully calibrated to match soil-crop demands, thereby mitigating the risks of soil salinity or environmental pollution. To minimize nitrate leaching and maximize its utilization by plants, it is generally recommended to apply manure in the spring (Asadu et al., 2024).

For optimal production of crops like cabbage, potatoes, and tomatoes, organic fertilizers are best incorporated directly into the soil. In contrast, for root crops such as carrots and beetroot, it is often more beneficial to apply organic fertilizers to the preceding crop in the rotation. The use of fresh manure, which may contain high concentrations of readily available nitrogen and salts, should be avoided as it can cause root damage and reduce the crop's natural resistance to pests (Majhi et al., 2024).

CONCLUSIONS

Cabbage production in Ethiopia faces systemic challenges, including soil degradation, climatic stressors, and inefficient fertilizer use. This review highlights the critical role of Integrated Nutrient Management (INM) in addressing these issues by combining the rapid nutrient release of inorganic fertilizers (e.g., NPK at 100-150 kg/ha) with the long-term soil-enhancing benefits of organic amendments (e.g., poultry manure at 10-15 tons/ha). Field trials demonstrate that INM significantly improves cabbage yields (20-30% increase) and head weight (e.g., 940.4 g vs. 374.4 g in controls), while enhancing soil organic carbon and microbial activity. However, adoption barriers persist, including limited farmer knowledge, inadequate extension services, and a lack of localized research on optimal fertilizer ratios for Ethiopia's diverse agroecological zones.

To overcome these challenges, future efforts must prioritize context-specific INM strategies. For instance, a balanced ratio of 70% organic and 30% inorganic fertilizers has shown promise in harmonizing productivity and sustainability. Additionally, addressing socioeconomic constraints such as input costs and market access is essential for widespread adoption. By integrating scientific evidence with farmer-centric approaches, Ethiopia can leverage INM to enhance cabbage productivity, improve soil health, and achieve long-term food security.

Recommendations

To promote the adoption of Integrated Nutrient Management (INM) for cabbage production, several key recommendations are proposed:

Optimal Fertilizer Ratios: For smallholder farmers, a combination of 10–15 tons/ha poultry manure (organic) and 100 kg/ha NPK (inorganic) is recommended to maximize yield and soil health. Region-specific adjustments should consider soil fertility levels (e.g., 150 kg NPSB + 100 kg urea/ha for fertile soils).

Farmer Education: Develop training programs emphasizing the cost-benefit analysis of INM, including practical demonstrations of fertilizer blending (e.g., 70% organic + 30% inorganic) and application timing (e.g., split urea applications).

Policy Support: Governments may subsidize organic fertilizers and incentivize INM adoption through tax breaks or grants, particularly for high-demand varieties like *Copenhagen*.

Research Priorities: Conduct long-term studies on soil-crop dynamics under INM, focusing on highland vs. mid-altitude zones, and evaluate innovative inputs like biochar-compost blends.

Consumer Awareness: Highlight the nutritional and environmental benefits of INM-grown cabbage to create market demand and support premium pricing for sustainably produced crops.

By addressing these gaps, Ethiopia can unlock the full potential of INM to achieve sustainable cabbage production and food security.

CRediT Authorship Contribution Statement

The author affirms sole responsibility for the conception of the study, the presentation of results, and manuscript preparation.

Declaration of Competing Interest

The author declares that there is no conflict of interest.

Data Availability

The data used in this study are available upon request.

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