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Compost Science & Utilization

ISSN: 1065-657X (Print) 2326-2397 (Online) Journal homepage: www.tandfonline.com/journals/ucsu20

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To cite this article: Tiblets Gebregergs, Girma Gezimu Gebre, Mohammedawel Jeneto Mohammed, Desalegn Tegegne & Stefan Sieber (24 Aug 2026): Effect of Integrated Use of Organic and Inorganic Fertilizer on Wheat Productivity in Tigray, Ethiopia, Compost Science & Utilization, DOI: 10.1080/1065657X.2026.2715548

To link to this article: https://doi.org/10.1080/1065657X.2026.2715548

Published online: 24 Aug 2026.

COMPOST SCIENCE & UTILIZATION
https://doi.org/10.1080/1065657X.2026.2715548

Effect of Integrated Use of Organic and Inorganic Fertilizer on Wheat Productivity in Tigray, Ethiopia

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ABSTRACT
Declining soil fertility is a major constraint to wheat production in Tigray, Ethiopia, threatening food security and rural livelihoods. This study evaluated the effects of integrated organic and inorganic nutrient management on the growth, yield, and nutrient uptake of bread wheat (Shina, HAR-1868) in Laelay Maichew Woreda during the 2019 cropping season. A factorial experiment with four compost levels (0, 4, 8, and 12 t/ha) and three chemical fertilizer rates (0, 50, and 100 kg/ha of urea and DAP) was laid out in a randomized complete block design with three replications. Soil and compost analyses indicated low fertility in the experimental site, with deficiencies in nitrogen, phosphorus, and organic matter, while the compost was rich in nitrogen and organic carbon. Results showed that both chemical and compost fertilizers, individually and in combination, significantly improved wheat phenology, growth parameters, grain and biomass yield, and nutrient uptake. The combined application of 12 t/ha compost and 100 kg/ha chemical fertilizer produced the highest grain yield (46.17 q/ha), above-ground biomass (102.50 q/ha), and nutrient uptake (N: 97.84 kg/ha; P: 5.54 kg/ha), outperforming sole applications. Grain yield was positively correlated with plant height, panicle length, number of tillers, seeds per panicle, biomass, and straw yield, and negatively correlated with days to emergence, heading, and maturity. The study demonstrates that integrated nutrient management using locally available compost and recommended chemical fertilizers can enhance wheat productivity, improve soil fertility, and optimize nutrient use efficiency under Tigray conditions. Adoption of such strategies could contribute to sustainable wheat production and food security in the region.

1. Introduction

As the global population continues to grow and climate change presents formidable challenges, food security and agricultural sustainability have emerged as critical global concerns (Qiang et al. 2025). Wheat, one of the most vital staple crops, plays a key role in improving human well-being by contributing to increased productivity and sustainable development. This is also true in Ethiopia, where wheat ranks as the third most important cereal crop after tef (*Eragrostis tef*) and maize (*Zea mays* L.) (Melak et al. 2025; Senbeta and Worku 2023).

Ethiopia faces persistent soil fertility decline that threatens both agricultural productivity and rural livelihoods. Land degradation caused by rapid population growth, unsustainable land use practices, deforestation, overgrazing, and climate variability has severely reduced soil fertility (Njeru, Grey, and Kilawe 2016; Schmitter et al. 2016). In regions such as Tigray, soil erosion, nutrient depletion, and low organic matter have been identified as the primary constraints to crop production, exacerbating food insecurity and rural poverty (Kraaijvanger and Veldkamp 2015; Mekuria et al. 2018; Tegegne, Damtie, and

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Shumye 2025). These challenges highlight the urgent need for integrated soil fertility management approaches that combine local knowledge, sustainable land management practices, and modern technologies to restore soil health, enhance agricultural resilience, and ensure food security in Ethiopia.

Empirical studies indicate that both organic and inorganic fertilizers improve wheat yield. Organic fertilizers enhance soil health and long-term productivity, while inorganic fertilizers provide immediate nutrient availability. A combined approach, known as Integrated Nutrient Management (INM), generally produces the best results, improving both short-term crop productivity and long-term soil quality by enhancing nutrient uptake, increasing soil organic matter, and providing a balanced nutrient supply (Chala and Obsa 2019; Desalegn 2022; Habtamu et al. 2024; Qiang et al. 2025; Wang et al. 2024).

Numerous studies show that soils in Tigray are deficient in nitrogen and phosphorus (Amede, Belachew, and Geta 2001; Ethiopian Soil Information System (EthioSIS) 2014; Food and Agriculture Organization (FAO) 2015; Kebede and Yamoah 2009; Mitiku, Berhanu, and Amare 2003; Tegene 1996; Teklu, Haile, and Fitsum 2004; Tekulu, Taye, and Assefa 2020). In Laelay Maichew Woreda of the Tigray region, wheat is a major crop, but low soil fertility constrains its yield. Even in experimental plots, yields remain below potential levels (Gebregergs 2024). The large gaps between actual and potential yields are largely due to poor soil fertility management, climatic factors, and other agronomic practices. While the application of organic and inorganic fertilizers is a key strategy for improving soil fertility and crop productivity, the combined application practices are often not tailored to specific crops and soil types, and local social preferences are frequently overlooked.

Although chemical fertilizers are essential for achieving high yields in degraded soils, using locally available organic resources offers a more sustainable approach to maintaining soil health. However, organic materials are often used for multiple purposes, such as fuel or animal feed. Additionally, because organic inputs generally supply lower nutrient concentrations than inorganic fertilizers, farmers would need to apply them in large quantities, making it impractical to rely on organic sources alone. Therefore, INM, which combines organic and inorganic fertilizers, provides a more balanced and efficient approach to enhance productivity, improve nutrient use efficiency, and optimize the utilization of available resources (Desalegn 2022; Esubalew, Amare, and Molla 2023; Habtamu et al. 2024; Hammad et al. 2020; Qiang et al. 2025; Quddus et al. 2025; Raju et al. 2024; Roba 2018; Tehulie 2020; Wang et al. 2024).

Accordingly, the general objective of this study is to evaluate the effects of integrated applications of compost and chemical fertilizers (urea and DAP) on wheat yield and its components. The specific objectives are: (i) to evaluate the effect of different compost levels and inorganic fertilizer rates on the growth and yield components of bread wheat; (ii) to determine the influence of combined application of compost and chemical fertilizers on wheat grain and above-ground biomass yield; and (iii) to assess the effect of integrating organic and inorganic fertilizers on nutrient uptake in wheat.

2. Materials and Methods

2.1. Study Area

This study was conducted during the 2019 cropping season in Tabia Hatsebo, Lesaliso, and Myweini, which are located in Laelay Maichew Woreda, Central Zone of Tigray, Ethiopia (see Figure 1). These sites were selected because wheat is one of the major cereal crops grown in the area, and farmers commonly apply both organic and inorganic fertilizers to improve soil fertility and enhance productivity. The experimental site, located at the farmers' training center in Hatsebo, lies between latitudes 13°15′00″ and 14°39′20″ N, longitudes 38°34′00″ and 39°25′09″ E, at an elevation of 2,080 meters above sea level (Gebregergs 2024).

The area has suitable climatic conditions for wheat cultivation, and its agroecology is classified as *weinadega*. The mean annual temperature ranges from 12°C to 28°C, while the average annual rainfall varies between 500 and 900 mm. The rainy season typically begins in June and ends in September (Gebregergs 2024).

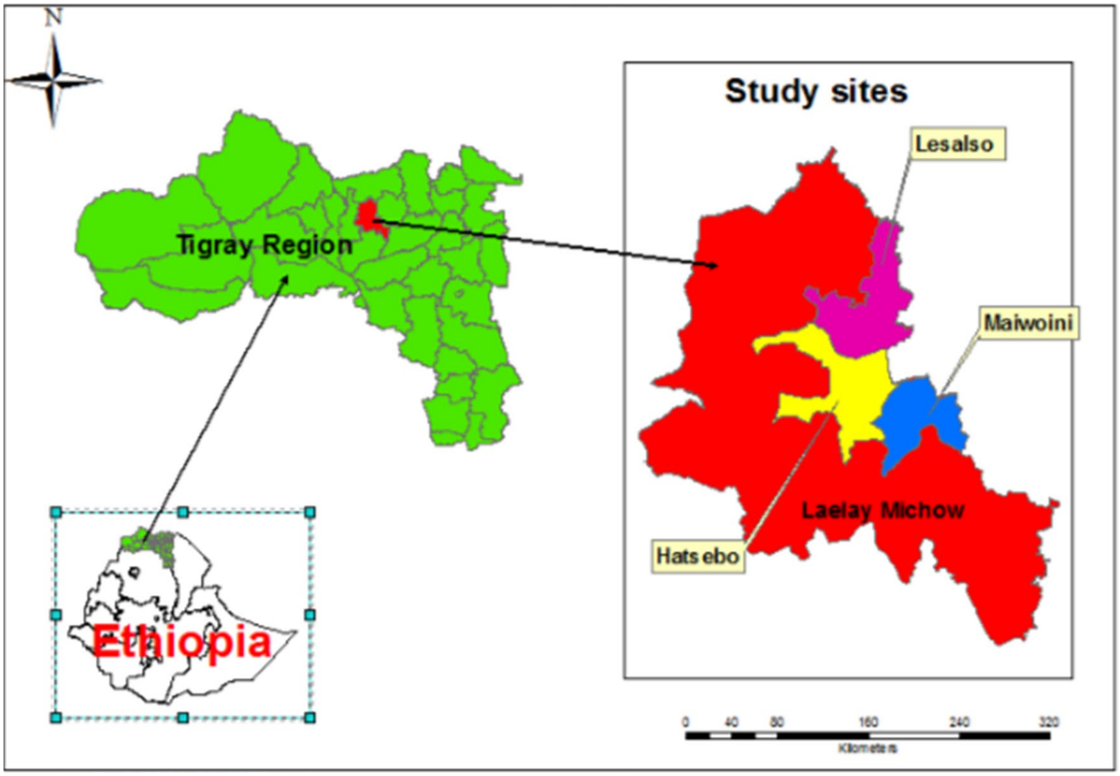

Figure 1. Location map of study area.

Pre-sowing soil texture analysis indicates that the soil at the experimental site is classified as clay. The dominant soil types in the study area include Vertisol (38.4%), Cambisol (24.76%), and Regosol (21.29%) (Gebregergs 2024). Major crops cultivated in the woreda include teff, wheat, barley, field pea, faba bean, lentil, fenugreek, and maize, with teff and wheat serving as the primary staple foods for the local population.

2.2. Experimental Approaches

An improved bread wheat variety, Shina (HAR-1868), was used as the test crop. This variety has been widely adopted in the study area since its introduction by the Axum Agricultural Research Center in 2007, with a recommended seed rate of 150 kg/ha (Axum Agricultural Research Center (AxARC) 2007). It was originally released by Adet and Holeta Agricultural Research Centers in 1999. The variety has a potential yield range of 35–60 qt/ha, a plant height ranging from 52–77.2 cm and is adapted to altitudes between 1800 and 2550 masl (Axum Agricultural Research Center (AxARC) 2007).

The treatments consisted of a factorial combination of four levels of compost fertilizer and three levels of chemical fertilizer (Urea and DAP), resulting in a total of 12 treatment combinations. The experiment was laid out in a randomized complete block design with a 4×3 factorial arrangement and three replications. Each plot measured $3\,m \times 3$ m (9 m^2), covering a total experimental area of 564 m^2. Treatments were assigned randomly to experimental units within each block. The spacing between blocks was 1.5 m, while plots within a block were 1 m apart. The spacing between wheat rows within a plot was 20 cm.

The chemical fertilizers used included Di-Ammonium Phosphate (DAP; 18% nitrogen (N), 46% phosphorus (P)) and Urea (46% N). The full dose of DAP and half of the Urea were applied at sowing, while the remaining Urea was side dressed at the panicle initiation stage of the crop. The compost was sourced from Hatsebo extension center and prepared at the farmers training center using grass, weeds, crop residues, animal manure, and other farm wastes. The materials were composted for two years before application, and full doses of each compost level were applied at sowing. Chemical fertilizers were applied at different rates alongside compost treatments, providing essential nutrients for crop growth.

Three levels of chemical fertilizer (CF) were used:

i. CF1 = 0 kg/ha (control)
ii. CF2 = 50 kg/ha Urea (23 kg N) + 50 kg/ha DAP (9 kg N & 23 kg P)
iii. CF3 = 100 kg/ha Urea (46 kg N) + 100 kg/ha DAP (18 kg N & 46 kg P)

Four levels of organic fertilizer (compost) were:

i. Com1 = 0 t/ha
ii. Com2 = 4 t/ha
iii. Com3 = 8 t/ha
iv. Com4 = 12 t/ha

2.3. Compost Preparations

Compost for the experiment was prepared near the study area using locally available crop residues and organic wastes through three main steps. First, different residues from livestock dung, plants, and other wastes were collected and chopped into smaller pieces to facilitate decomposition. Second, the residues were layered with animal manure and soil, maintaining proper moisture and aeration through regular turning (the pile was placed at a distance from houses to avoid pollution). Third, the pile was allowed to mature until it became dark, crumbly, and free from foul odor, indicating readiness for field application. This compost was then applied at different rates in combination with inorganic fertilizers to evaluate its effect on wheat production in the study area.

2.4. Data Collection

2.4.1. Soil Sampling and Analysis

To analyze soil physical and chemical properties, fifteen sub-samples were collected from the entire experimental field using an auger at a depth of 30 cm before planting. The sub-samples were mixed to form a composite sample. After harvest, 36 soil samples were collected by taking five sub-samples from each plot in each replication, forming a composite sample of approximately 1 kg per plot.

Soil analyses were conducted at the Tigray Agricultural Research Institute soils laboratory to determine soil moisture and texture before sowing, as well as pH, nitrogen (N), phosphorus (P), cation exchange capacity (CEC), electrical conductivity (EC), organic matter, and available potassium (K) for both pre-sowing and post-harvest samples. Available potassium in the post-harvest samples was analyzed at the Mekelle University soil laboratory.

Soil samples were air-dried, crushed, and passed through a 2 mm sieve before analysis. Soil moisture content was determined using the gravimetric method. Fresh soil weight was measured at sampling, followed by oven-drying at 105°C for 24 h to obtain the dry weight. Gravimetric soil moisture, expressed as a percentage of dry weight, was calculated as:

$$\text{Moisture}(\%) = \frac{(\text{Fresh Weight} - \text{Dry Weight})}{\text{Dry Weight}} \times 100 \quad (1)$$

Particle size distribution was determined using the hydrometer method (Day 1965; Gee and Bauder 1986). Soil chemical properties were analyzed for both pre- and post-sowing samples. Soil pH and compost content were measured in a 1:2.5 soil-to-water suspension using a pH meter (Jackson 1958). Soil organic carbon (SOC) was determined by the (Walkley and Black 1934), and soil organic matter (SOM) was calculated by multiplying SOC by 1.724. Cation exchange capacity (CEC) was measured using the ammonium acetate method (Okalebo, Gathua, and Woomer 1993). Available phosphorus was determined using the Olsen method (Olsen, Cole, and Watanabe 1954), while available potassium was extracted with Morgan solution and measured using a flame photometer. Total nitrogen (N) was determined using the Kjeldahl method (Dewis and Freitas 1970), and electrical conductivity (EC) was measured using an EC meter (Sertsu and Bekele 2000).

2.4.2. Grain Sampling and Nutrient Analysis

Grain samples were randomly collected from harvested plants in each plot to determine nitrogen (N) and phosphorus (P) content. Samples were air-dried, sieved through a 1 mm mesh, and the resulting powder was sealed in plastic for analysis. Nitrogen content was determined using the Kjeldahl digestion method (Helrich 1990), while phosphorus content was measured using the ashing method. Total uptake of nitrogen and phosphorus was calculated by multiplying grain yield (kg/ha) by the corresponding nutrient concentration (mg/kg) for each treatment as follows:

$$\text{N and P uptake}\left(\text{kg}/\text{ha}\right) = \frac{\text{N and P concentration} \times \text{Yield}\left(\text{kg}/\text{ha}\right)}{100} \quad (2)$$

2.4.3. Phenological Observations

Phenological data were recorded at key growth stages, including the initial/emergence stage (approximately 10% ground cover), flowering/middle stage (30–50% ground cover), and harvest/maturity stage (when the crop fully covered the plot and was ready for harvest) as described by Tegegne, Schmitter, et al. (2025). The 50% stage of each phenological development, referring to the percentage of plot area covered by the crop, was estimated when crop emergence ceased or when most plants reached the three to four leaf stage. All observations were recorded as the number of days from sowing.

2.4.4. Crop Growth Measurements

Crop growth parameters, including plant height, panicle length, number of effective tillers per plant, and number of seeds per panicle, were measured from 10 randomly selected plants per plot, and the mean values were calculated for each plot. Plant height was recorded from ground level to the tip of the plant. The number of seeds per panicle was determined by counting all seeds on each sampled panicle.

2.4.5. Harvest and Yield Determination

Harvesting was conducted when all plants in a plot had matured and leaves turned yellow. At this stage, all plants from the net plot area (4 m^2) were harvested and grain yield (economic) was measured. Biomass and grain yields were weighed using sensitive balance after sun drying the straw and grain for about two weeks after harvest expressed in quintal/ha. And straw yield and Harvest index (HI) calculated as Total above ground biomass yield minus grain yield and as the ratio of bread wheat grain yield to total above ground biomass yield multiplied by 100 and was expressed in percentage respectively as shown the following formula

$$\text{SY}\left(\text{q}/\text{ha}\right) = \text{AGBY}\left(\frac{\text{q}}{\text{ha}}\right) - \text{GY}\left(\frac{\text{q}}{\text{ha}}\right) \quad (3)$$

where SY = Straw yield, AGBY = Aboveground biomass yield and GY = Grain Yield

$$\text{HI}\left(\%\right) = \frac{\text{GY}\left(\text{q}/\text{ha}\right))\ \text{x}\ 100}{AGBY\left(q/ha\right)} \quad (4)$$

2.5. Data Analysis

All agronomic data on crop and soil parameters were subjected to analysis of variance using a procedure appropriate for a factorial experiment in a randomized complete block design, as suggested by Gomez and Gomez (1984). The analysis was performed using GenStat 13th statistical software (VSN-International 2009). When significant differences were detected among treatments, mean separation was conducted using Duncan's Multiple Range Test at a 5% probability level. Additionally, simple correlation analysis was performed to determine the relationships between various agronomic parameters (yield and yield components) and soil nutrient properties.

3. Results and Discussion

3.1. Physical and Chemical Properties of Soil and Compost before Sowing

Physical and chemical analyses were conducted on the surface composite soil (0–30 cm) of the experimental field (Table 1). The total soil moisture content at the time of sowing was 30% on a weight basis. The textural class of the surface soil was clay, with a particle size distribution of 25% sand, 33% silt, and 42% clay.

The chemical characteristics of the soil were as follows: pH 7.7 (slightly alkaline), available phosphorus (Av. P) 3.3 ppm, and total nitrogen (TN) 0.105%. According to Foth (1990), an available phosphorus content of 3.3 ppm is very low, and the organic matter content of 1.8% and total nitrogen of 0.10% are considered low. The cation exchange capacity (CEC) was 55.2 meq/100 g, which is classified as low according to the United Nations Economic Commission for Africa (UNECA 1964). Organic carbon was 1.05%, also considered deficient (Defoer et al. 2000). These results indicate a need to apply additional organic or inorganic nutrient sources to improve soil fertility and support crop growth. The low organic carbon in the soil could be attributed to the removal of crop residues and limited incorporation of biomass, contributing to the low organic matter and total nitrogen content.

The chemical composition of the compost used in the experiment was determined through laboratory analysis (Table 1). The compost contained 3.9% organic carbon, 6.72% organic matter (high), 2.31% nitrogen (very high), 1.35 ppm available phosphorus (high), and 25.0 ppm available potassium (UNECA 1964). These results indicate that compost is nutrient-rich, particularly in nitrogen, organic matter, and organic carbon, with adequate levels of phosphorus and potassium, making it an effective organic fertilizer to improve soil fertility and support crop growth.

3.2. Effect of Compost and Chemical Fertilizers on Wheat Yield and Yield Attributes

The results of the main effects of compost, chemical fertilizer, and their interactions on days to 50% emergence are presented in Table 2. The average values of each treatment showed that chemical fertilizer significantly influenced seedling emergence. Wheat seedlings treated with chemical fertilizer emerged earlier (5.9 days) compared to the control (7.08 days). The application of compost alone, however, showed no significant difference among treatments, and days to emergence varied irregularly across compost rates. Overall, chemical fertilizer accelerated emergence compared to compost alone, likely due to its

Table 1. Physical and chemical properties of soil and chemical properties of compost in the experimental site before sowing.

Soil & compost Characteristics	Texture			Class	PH	O.C	O.M	CEC	Av.P	Av.K	TN	EC
	Sand	Silt	Clay									
Unit	%	%	%			%	%	Meq/100Kg	Ppm	Ppm	%	dsm^{-1}
Content of soil	25	33	42	Clay	7.7	1.05	1.8	55.2	3.3	9.53	0.105	0.16
Content of compost					7.15	3.9	6.72	6.72	1.35	25.6	2.31	4.4

Note: O.C refers to organic carbon, O.M refers to organic matter, Av. P refers to available phosphorus,.
Av. K refers to available potassium and TN refers to total Nitrogen and EC refers to electrical conductivity.

Table 2. Effects of combined application of compost and chemical fertilizer on wheat parameters, 2019.

Treatments	Treatment combinations		DE	DH	DM	PH	PL	NT	NSPP	AGBY	GY	SY	HI
	Compost (t/ha.)	CF (kg/ha.)											
Trt1	0	0	7.333c	63.00^{dd}	99.33^{e}	45.93^{a}	6.000^{a}	2.63^{a}	31.67^{a}	39.37^{ab}	17.61^{a}	43.95^{ab}	14.06^{a}
Trt2	0	50/50	6.333^{abc}	57.00^{b}	97.00^{cde}	60.17^{c}	6.400^{ab}	3.03^{abc}	61.08^{cd}	39.70^{ab}	33.25^{bc}	45.42^{b}	27.83^{cd}
Trt3	0	100/100	6.000^{ab}	55.00^{a}	93.67^{b}	64.17^{cd}	8.033^{d}	3.63^{bcde}	91.08^{gh}	44.60^{d}	49.73^{f}	45.39^{b}	41.35^{gh}
Trt4	4	0	7.333^{c}	62.67^{d}	97.33^{de}	55.30b	7.167^{bcd}	2.800^{a}	50.83^{b}	37.37^{a}	29.47^{b}	42.05^{ab}	21.37^{b}
Trt5	4	50/50	6.667^{abc}	56.00^{ab}	95.33^{bcd}	62.20c	7.567^{cd}	3.00^{ab}	74.17^{e}	39.57^{ab}	41.17^{de}	44.50^{b}	33.00^{e}
Trt6	4	100/100	6.333^{abc}	55.33^{a}	94.00^{b}	67.23de	7.167^{bcd}	3.27^{abcd}	84.17^{fg}	44.07^{cd}	45.76^{ef}	45.61^{b}	38.41^{fgh}
Trt7	8	0	6.667^{abc}	61.00^{c}	97.00^{cde}	55.43b	6.733^{abc}	3.267^{abcd}	54.17^{bc}	40.79^{abc}	30.05^{b}	44.80^{b}	24.12^{bc}
Trt8	8	50/50	6.333^{abc}	55.67^{ab}	94.67^{bc}	68.37de	7.733^{cd}	4.000^{e}	79.17^{ef}	39.43^{ab}	42.98^{e}	45.74^{b}	36.18^{ef}
Trt9	8	100/100	5.667^{a}	54.67^{a}	91.00^{a}	64.43 cd	7.500^{cd}	3.733^{de}	98.33^{hi}	44.13^{cd}	55.67^{g}	43.39^{ab}	42.67^{hi}
Trt10	12	0	7.000^{bc}	60.00^{c}	95.00^{bcd}	54.47b	6.133^{a}	2.667^{a}	65.83^{d}	39.27^{ab}	37.11^{cd}	43.63^{ab}	28.72^{d}
Trt11	12	50/50	6.667^{abc}	55.00^{a}	94.00^{b}	64.33 cd	7.867^{d}	3.500^{bcde}	95.83^{hi}	41.73^{bcd}	58.03^{g}	39.44^{a}	37.81^{fg}
Trt12	12	100/100	5.667^{a}	54.67^{a}	89.33^{a}	70.97e	8.200^{d}	3.667^{cde}	102.50^{i}	48.17^{e}	56.33^{g}	45.0^{b}	46.17^{i}
SEM(±)			0.3138	0.479	0.770	1.322	0.3134	0.1990	2.733	1.165	1.671	1.439	1.437
LSD(0.05)			0.9204	1.406	2.258	3.878	0.9191	0.5836	8.015	3.417	4.901	4.221	4.215
CV (%)			8.4	1.4	1.4	3.7	7.5	10.6	6.4	4.9	7.0	5.7	7.6

Characters (a, b, c, ab, etc.) indicate statistical groupings that identify differences or similarities among values of treatments.

faster nutrient release and better interaction with soil moisture and temperature. The combined application of compost and chemical fertilizer produced the shortest time to 50% emergence (5.66 days) in plots that received 100 kg/ha of chemical fertilizer and 8 t/ha of compost. In contrast, the longest emergence period (7.33 days) occurred in control plots with no chemical fertilizer and 4 t/ha compost, highlighting the advantage of integrated nutrient management in promoting early crop establishment. This clearly demonstrates that chemical fertilizers hasten seed emergence and germination in wheat.

Regarding days to 50% heading, analysis of variance revealed significant differences ($p < 0.001$) for both the main effects of compost and chemical fertilizer, but no significant interaction effect between them. Plots treated with chemical fertilizer reached 50% heading sooner (54.9 days) than those treated with compost alone (56.6 days). Among chemical fertilizer treatments, the shortest time to heading (54.9 days) was observed at the highest rate (100 kg/ha of urea and DAP), while the longest period (61.7 days) occurred in the control. Application of compost alone at 12 t/ha significantly reduced the heading date (56.6 days) compared to the control (58 days), while lower compost rates (4 and 8 t/ha) showed no significant differences. This may be due to the relatively low nutrient release rate or insufficient compost application.

Considering the interaction effect of compost and chemical fertilizer, the shortest time to 50% heading (54.7 days) was recorded from the treatment that received a combination of 8 t/ha compost and 100 kg/ha chemical fertilizer, whereas the longest time (63 days) was observed in the control treatment that received neither compost nor chemical fertilizer.

The results for days to 50% maturity also indicated significant effects ($p < 0.001$) of compost and chemical fertilizer, both individually and in combination. For the main effect of chemical fertilizer, earlier maturity was observed at higher fertilizer rates, while the control took the longest time (97.2 days). Similarly, in the main effect of compost, the shortest maturity period (92.8 days) occurred at the highest compost rate (12 t/ha), while the control plots had the longest (96.8 days). This may be attributed to the readily available nutrients in chemical fertilizer. For the combined application, the shortest days to maturity (89.3 days) were obtained from the treatment receiving 12 t/ha of compost and 100 kg/ha of chemical fertilizer, while the longest period (99 days) was recorded in the unfertilized control. These findings are consistent with the reports of Orkaido (2004) and Dechasa (2022), who noted that chemical fertilizer application promotes earlier crop maturity and higher yields in maize.

The application of compost and chemical fertilizer, whether individually or in combination, significantly increased wheat plant height. The highest plant height (66.7 cm) was recorded with the higher chemical fertilizer rate (100 kg/ha), while the shortest (52 cm) was observed in control. This indicates that plant height increases with higher fertilizer application. For the main effect of compost, the tallest plants (63.26 cm) were obtained from 12 t/ha of compost, while the shortest (56.76 cm) occurred in the control. Although no significant difference was observed among the 4, 8, and 12 t/ha compost treatments, an increasing trend in plant height was evident with higher compost rates. When comparing main effects, chemical fertilizer had a significantly greater effect on wheat height than compost alone.

For the interaction effect, a significant difference was also observed: the tallest plants (68.32 cm) were recorded from the treatment that received 8 t/ha of compost and 50 kg/ha of chemical fertilizer, whereas the shortest plants (45.93 cm) were from the unfertilized control. Comparing both main and interaction effects, the combined application of compost and chemical fertilizer had a stronger positive effect on plant height than either input alone (Table 2).

The main and interaction effects of compost and chemical fertilizer on panicle length of bread wheat were assessed. A significant difference ($p < 0.001$) was observed for chemical fertilizer applied alone. The highest mean panicle length (7.72 cm) was recorded with 100 kg/ha of urea and DAP, while the shortest (6.5 cm) was observed in the control. Panicle length increased as the chemical fertilizer rate rose from 0 to 100 kg/ha. Although the main effect of compost on panicle length was not statistically significant ($p > 0.05$), an increasing trend was observed as compost rates increased from 0 to 12 t/ha. Overall, as shown in Table 2, chemical fertilizer had a greater effect on panicle length than compost. This may be attributed to the slow nutrient release from compost. The interaction between compost and chemical fertilizer did not show a significant effect on panicle length.

The number of wheat tillers were significantly affected by the main effects of compost and chemical fertilizer, but not by their combined application. A higher average number of tillers (4) was recorded with the highest dose of chemical fertilizer, while the lowest (3) occurred in the control. Under compost application alone, the highest number of tillers (3) was obtained from 12 t/ha of compost, and the lowest (3) from the control (Table 2). The combined application of compost and chemical fertilizer did not significantly influence tiller numbers.

The number of seeds per panicle (NSPP) increased significantly with the application of chemical fertilizer alone and in combination with compost ($p < 0.01$). Compost alone, however, did not significantly affect NSPP ($p > 0.05$). The highest mean NSPP (45.24) was recorded at 100 kg/ha of chemical fertilizer, while the lowest (39.2) was from the control. The combined application of compost and chemical fertilizer produced the highest NSPP (48.17) at 12 t/ha of compost and 100 kg/ha of fertilizer, which was significantly greater than all other treatments. This indicates that integrated nutrient management has a stronger positive impact on seed formation than either input used alone.

Above-ground biomass of wheat was significantly influenced ($p < 0.01$) by both the individual and combined applications of compost and chemical fertilizer. Compared with the control, biomass yield increased significantly with chemical fertilizer rates of 50 and 100 kg/ha and compost rates of 8 and 12 t/ha (Table 2). The lowest mean value (50.62 q/ha) was recorded in the control, while the highest (94.56 q/ha) was obtained with the highest fertilizer rate. For compost alone, the highest biomass (88.06 q/ha) and the lowest (61.28 q/ha) were recorded at 12 t/ha and the control, respectively. The combined application of 12 t/ha compost and 100 kg/ha chemical fertilizer resulted in the highest above-ground biomass (102.50 q/ha), while the lowest (31.67 q/ha) occurred in the control. However, no significant difference was found between the two combined rates (12 t/ha + 50 kg/ha and 8 t/ha + 100 kg/ha). Overall, the combined application produced higher biomass yield than compost or fertilizer alone. This agrees with (Rizwan et al. 2006), who reported that compost enriched with N and L-TRP, combined with 50% supplementary N fertilizer, significantly increased fresh biomass (11.8%), cob weight (12.6%), and grain yield (13.6%) compared to the full N fertilizer dose.

Analysis of variance showed that compost and inorganic fertilizer, applied either individually or in combination, significantly increased wheat grain yield ($p < 0.05$). For the sole application of chemical fertilizer, the highest yield (42.0 q/ha) was recorded at 100 kg/ha, while the lowest (22.07 q/ha) occurred in the control, an increase of 91% over the control. For compost alone, the highest yield (37.57 q/ha) was obtained at 12 t/ha, and the lowest (27.75 q/ha) in the control. Comparing the two main effects, chemical fertilizer produced higher grain yield than compost, likely due to its immediate nutrient availability, whereas compost releases nutrients more slowly.

For the combined treatment, the highest grain yield (46.17 q/ha) was recorded at 12 t/ha compost and 100 kg/ha chemical fertilizer, while the lowest (14.61 q/ha) was from the unfertilized control. Although the mixed application of 8 t/ha compost and 50 kg/ha chemical fertilizer (42.7 q/ha) was not significantly different from the highest combined rate, both integrated treatments outperformed the individual applications. These results align with findings by Ouédraogo, Mando, and Zombré (2001) in Burkina Faso, who reported 45% and 300% increases in sorghum yield with 5 and 10 t/ha compost, respectively, compared with no compost. Similarly, (Rizwan et al. 2006) observed that compost enriched with 25% N and L-TRP applied alongside 50% N fertilizer significantly improved wheat and maize growth and yield compared to full N fertilizer alone.

The main effects of compost and chemical fertilizer, as well as their combination, also significantly influenced straw yield ($p < 0.01$) (Table 2). The highest straw yield (51.8 q/ha) was obtained with 100 kg/ha chemical fertilizer, while the lowest (28.56 q/ha) was recorded in the control, an increase of 55%. For compost, the highest yield (50.49 q/ha) occurred at 12 t/ha, and the lowest (33.53 q/ha) in the control, representing a 66.4% increase. The combined application of compost and chemical fertilizer yielded the highest straw production (58.33 q/ha) at the highest compost and half-fertilizer rates, while the lowest (17.61 q/ha) was from the unfertilized control, an increase of 30.2%. Although no significant differences were found among the combined rates ($p > 0.05$), the integrated application produced higher straw yield than either fertilizer or compost alone.

3.3. Correlation of Grain Yield and Some Yield Attributes of Wheat

The correlation coefficients among the traits studied are presented in Table 3. Several yield-related parameters, including panicle length (PL), plant height (PH), number of tillers per plant (NT), number of seeds per panicle (NSPP), above-ground biomass yield (AGBY), grain yield (GY), and straw yield (SY), were positively and significantly correlated ($p < 0.001$) with both total biological yield and grain yield.

Grain yield (q/ha) showed positive and significant correlations with number of tillers per plant ($r = 0.62^{**}$), plant height ($r = 0.87^{**}$), panicle length ($r = 0.66^{**}$), number of seeds per panicle ($r = 0.68^{**}$), above-ground biomass yield ($r = 0.95^{**}$), and straw yield ($r = 0.86^{**}$). These relationships indicate that the application of compost and chemical fertilizers enhanced grain yield by improving key yield components of wheat. Similar observations were reported by Navneet, Sikarwar, and Kandalkar (2019), who found positive and highly significant correlations between seed yield per hectare and traits such as final plant height, number of seeds per capsule, and number of seeds per plant in sesame.

Conversely, grain yield showed significant negative correlations with days to emergence ($r = -0.68^{**}$), days to heading ($r = -0.91^{**}$), and days to maturity ($r = -0.85^{**}$), suggesting that earlier crop development is associated with higher yields. Moreover, plant height (PH), above-ground biomass yield (AGBY), and straw yield (SY) were highly and positively correlated ($p < 0.01$) with nearly all the measured traits, except for days to emergence, heading, and maturity. The number of seeds per panicle showed a positive but non-significant correlation with number of tillers per plant ($r = 0.43^{ns}$).

3.4. Effect of Compost and Chemical Fertilizers on N and P Concentration and Uptake on Wheat Grain Yield

The concentration of nitrogen in wheat grain was significantly influenced by the main effects of both compost and chemical fertilizer, while their interaction effect was not statistically significant ($p > 0.05$). Regarding the main effect of chemical fertilizer, the highest nitrogen concentration in wheat grain (18.99 g/kg) was obtained from the highest fertilizer rate (100 kg/ha), whereas the lowest (17.05 g/kg) was recorded in the control. However, the nitrogen concentration at the 50 kg/ha fertilizer rate was not significantly different from the control.

Table 3. The correlation matrix of yield and some yield components.

	DE	DH	DM	NT	PH	PL	NSPP	ABY	GY	SY
DE	1.0000	0.6400**	0.6015**	−0.5495**	−0.6579**	−0.5144*	−0.6367**	−0.6475**	−0.6677**	−0.5937
DH		1.0000	0.7192**	−0.5897**	−0.8674**	−0.6456*	−0.5844**	−0.8649**	−0.9050**	−0.7835**
DM			1.0000	−0.5897**	−0.8674**	−0.6456**	−0.5844**	−0.8649**	−0.8530**	−0.7715**
NT				1.0000	0.6352**	0.4979*	0.4303 ns	0.6486**	0.6196**	0.6309**
PH					1.0000	0.8077**	0.6639**	0.8284**	0.8744**	0.7449**
PL						1.0000	0.6426**	0.6523**	0.6620**	0.6060**
NSPP							1.0000	0.6644**	0.6814**	0.6121**
ABY								1.0000	0.9524**	0.9748**
GY									1.0000	0.8602**
SY										1.0000

** and ** indicate significant at 5% and 1% probability level, respectively; ns = non-significant; DE = days to 50% emergence; DF = days to 50% heading; DM = days to 50% maturity; PL = Panicle length; PH = plant height; NT = Number of tillers per plant; NSPP = Number of seeds per panicle; AGBY = above ground biomass yield; GY = Grain yield; SY = Straw yield.*

For the main effect of compost, a significant difference was observed between the highest compost rate (12 t/ha) and the control, resulting in nitrogen concentrations of 19.72 g/kg and 17.0 g/kg, respectively. Compost rates of 4 t/ha and 8 t/ha did not differ significantly from the control. Under the interaction effect of compost and chemical fertilizer, the highest grain nitrogen concentration (21.2 g/kg) was recorded at the combined application of 12 t/ha compost and 100 kg/ha chemical fertilizer, while the lowest (16.36 g/kg) was obtained in the control, an increase of 29.6% over the control.

Similarly, phosphorus concentration in wheat grain was influenced by both the main and interaction effects of compost and chemical fertilizer, as shown in Table 4. Phosphorus concentration increased with the application of higher chemical fertilizer rates. A significant difference was also observed between the control and the 12 t/ha compost treatment, while 4 t/ha and 8 t/ha compost rates did not differ significantly from the control. Overall, phosphorus concentration in the grain increased with both fertilizer types, either applied individually or in combination. The combined application of 8 t/ha or 12 t/ha compost with 50 or 100 kg/ha chemical fertilizer resulted in significantly higher phosphorus concentrations in the grain compared with individual fertilizer applications and the control.

Nitrogen and phosphorus uptake in wheat grain were significantly influenced by the main effects of compost and chemical fertilizer ($p < 0.001$), while their interaction effect was not statistically significant. For the main effect of chemical fertilizer, the highest nitrogen uptake in wheat grain (80.35 kg/ha) was recorded at the highest fertilizer rate (100 kg/ha), whereas the lowest (37.94 kg/ha) was observed in the control (zero fertilizer). Similarly, phosphorus uptake was highest (4.105 kg/ha) at 100 kg/ha of chemical fertilizer and lowest (1.917 kg/ha) in the control. Under the main effect of compost, the highest nitrogen uptake (75.16 kg/ha) was obtained at the 12 t/ha compost rate, while the lowest (47.91 kg/ha) was recorded in the control, representing a 56.9% increase. Although the 4 t/ha compost rate did not differ significantly from the control, an increasing trend in nitrogen uptake was observed as compost rate increased. This finding agrees with (Stahr 2010), who reported that the application of mineral fertilizer and 6.4 t/ha compost resulted in higher nitrogen uptake than 3.2 t/ha compost or the control.

Phosphorus uptake in wheat grain was also affected by compost application. The highest phosphorus uptake (3.952 kg/ha) was obtained from the 12 t/ha compost treatment, while the lowest (2.195 kg/ha) occurred in the control, an increase of 80% over the control. For the interaction effect of compost and chemical fertilizer, the highest nitrogen uptake (97.84 kg/ha) was recorded from the combined application of 12 t/ha compost and 100 kg/ha chemical fertilizer, while the lowest (23.03 kg/ha) was obtained from the unfertilized control (Table 5). Similarly, the

Table 4. Effect of compost and chemical fertilizers levels on concentration and up take of wheat grain.

	Concentration g/kg in wheat grain		Up take kg/ha in wheat grain	
Variable	N	P	N	P
CF (kg/ha.)				
0	17.05[a]	0.8523[a]	37.94[a]	1.917[a]
50	17.75[a]	0.8642[a]	60.33[b]	2.942[b]
100	18.99[b]	0.9652[b]	80.35[c]	4.105[c]
SEM (±)	0.306	0.0185	1.934	0.106
LSD (0.05)	0.897	0.0542	5.671	0.310
Compost(t/ha)				
0	17.00[a]	0.7791[a]	47.91[a]	2.195[a]
4	17.27[a]	0.8442[b]	53.89[a]	2.625[b]
8	17.74[a]	0.9227[c]	61.21[b]	3.181[c]
12		1.0296[d]	75.16[c]	3.952[d]
SEM (±)	0.353	0.0214	2.233	0.122
LSD (0.05)	1.036	0.0626	6.549	0.358

Characters (a, b, c) indicate statistical groupings that identify differences or similarities among values of treatments.

Table 5. Effect combined application of compost and chemical fertilizers on concentration and up take of wheat grain.

	Treatment combinations		Concentration g/kg in wheat grain		Up take kg/ha in wheat grain	
Treatments	Compost (t/ha.)	CF (kg/ha.)	N	P	N	P
Trt1	0	0	16.36[a]	0.7540[a]	23.03[a]	1.065[a]
Trt2	0	50/50	16.69[ab]	0.7533[a]	46.53[bcd]	2.087[bc]
Trt3	0	100/100	17.94[ab]	0.8300[ab]	74.18f[g]	3.432[fg]
Trt4	4	0	16.50[a]	0.8267[ab]	35.28[b]	1.769[b]
Trt5	4	50/50	17.08[ab]	0.8387[ab]	56.35[de]	2.774[def]
Trt6	4	100/100	18.24[abc]	0.8673[abc]	70.05f[g]	3.33f[g]
Trt7	8	0	17.36[ab]	0.9080[bc]	41.82[bc]	2.187[bcd]
Trt8	8	50/50	17.28[ab]	0.8960[bc]	62.46[ef]	3.239[efg]
Trt9	8	100/100	18.58[bc]	0.9640[c]	79.34[g]	4.116[h]
Trt10	12	0	17.98[ab]	0.9207[bc]	51.64[cde]	2.646[cde]
Trt11	12	50/50	19.97[cd]	0.9687[c]	75.99[g]	3.669[gh]
Trt12	12	100/100	21.20[d]	1.1993[d]	97.84[h]	5.542[i]
SEM(±)			0.612	0.0370	3.867	0.211
LSD(0.05)			1.795	0.1085	11.343	0.620
CV (%)			5.9	7.2	11.3	12.2

Characters (a, b, c, ab, etc.) indicate statistical groupings that identify differences or similarities among values of treatments.

highest phosphorus uptake (5.542 kg/ha) was recorded at the same combined treatment (12 t/ha compost + 100 kg/ha chemical fertilizer), and the lowest (1.065 kg/ha) from the treatment without compost and fertilizer. Overall, nitrogen uptake in wheat grain was higher than phosphorus uptake across all treatments, indicating that both compost and chemical fertilizers, either applied alone or in combination, enhanced nutrient accumulation in the grain.

4. Conclusion

The study demonstrated that the integrated application of compost and chemical fertilizers significantly enhanced wheat growth, yield, and nutrient uptake in the low-fertility soils of Laelay Maichew Woreda, Tigray, Ethiopia. Chemical fertilizer alone promoted faster emergence, early heading, and increased plant height, panicle length, and grain yield, whereas compost alone improved soil fertility and contributed to gradual yield improvements. However, the combination of compost and chemical fertilizers produced superior results compared to individual applications, significantly increasing grain and biomass yields, straw production, and nitrogen and phosphorus concentrations and uptake. Notably, the treatment with 12 t/ha compost combined with 100 kg/ha chemical fertilizer consistently resulted in the highest wheat productivity and nutrient accumulation, indicating the effectiveness of integrated nutrient management (INM) in enhancing both crop performance and soil fertility. These findings suggest that adopting INM strategies can sustainably improve wheat productivity in nutrient-depleted soils of Tigray, contributing to food security and long-term soil health. This study was limited to a single season; therefore, the future research should evaluate the sustainability of integrated fertilization practices over multiple seasons and assess their impact on soil fertility and environmental outcomes.

Consent to Publish

All authors confirm that the manuscript for submission and publication. Authors confirm that the content of the manuscript has not been published, or submitted for publication elsewhere.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Data Availability Statement

The data generated and analyzed for this study are available from the corresponding author upon request.

References

Amede, T., T. Belachew, and E. Geta. 2001. "Re-Versing Degradation of Arable Lands in Ethiopia Highlands." In *Managing African Soils, Series No. 23*. London: IIED.

Axum Agricultural Research Center (AxARC). 2007. "Wheat Variety Introduction and Adaptation Trials in L/Maichew, Central Zone of Tigray." Unpublished document.

Chala, G., and Z. Obsa. 2019. "Combination of Organic and Inorganic Fertilizer Improves Wheat Yields and Soil Properties on Nitisols of Central Highlands of Ethiopia." *Journal of Biology, Agriculture and Healthcare* 9 (4): 11–17.

Day, P. R. 1965. "Particle Fractionation and Particle-Size Analysis." In *Methods of Soil Analysis*, edited by C. A. Black. 545–567. Madison: American Society of Agronomy Inc.

Dechasa, M. 2022. "Effects of Blended NPSB and N Fertilizer Rates on Maize (*Zea mays* L.) Grain Yield and Yield Components in Chora District, Buno Bedele Zone, South Western Ethiopia." *World Journal of Applied Chemistry* 7 (1): 12–23.

Defoer, T., A. Budelman, C. C. Toulmin, and S. E. Carter. 2000. "'Building Common Knowledge.' A Resource Guide for Participatory Learning and Action Research (PLAR)." In *Managing Soil Fertility in Tropics: A Resource Guide for Participatory Learning and Action Research*, edited by T. Defoer and A. Budelman. Amsterdam, The Netherlands: Royal Tropical Institute.

Desalegn, M. 2022. "Review on the Integrated Use of Organic and Inorganic Fertilizers on Production and Soil Fertility in Ethiopia." *Journal of Biology, Agriculture and Healthcare* 12.

Dewis, J., and P. Freitas. 1970. *Physical and Chemical Methods of Soil and Water Analysis*. No.10, Rome, Italy: FAO Bull.

Esubalew, T., T. Amare, and E. Molla. 2023. "Quantification of Soil Nutrient Balance and Stock on Smallholder Farms at Agew Mariam Watershed in Northern Ethiopia." *Heliyon* 9 (4): e14832. https://doi.org/10.1016/j.heliyon.2023.e14832.

Ethiopian Soil Information System (EthioSIS). 2014. *Soil Fertility Status and Fertilizer Recommendation Atlas for Tigray Regional State*. Addis Ababa, Ethiopia: Ethio SIS.

Food and Agriculture Organization (FAO). 2015. *Status and Trends of Soil Resources in Ethiopia*. Rome: FAO.

Foth, D. H. 1990. *Fundamentals of Soil Science*. 8th ed. Hoboken: John Wiley and Sons Incorporated.

Gebregergs, T. 2024. "Effect of Integrated Use of Organic and Inorganic Fertilizer on Soil Chemical Properties in Laelaymaichew, Central Zone of Tigray, Ethiopia." *Asian Journal of Research and Review in Agriculture* 6: 607–621.

Gee, G. W., and J. W. Bauder. 1986. "Particle Size Analysis." In *Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods*, edited by A. Klute, 383–411. Madison, WI: Soil Science Society of America Inc, American Society of Agronomy, Inc.

Gomez, K. A., and A. A. Gomez. 1984. *Statistical Procedures for Agricultural Research*. 2nd ed. New York, USA: John Wiley and Sons.

Habtamu, M., E. Elias, T. Soromessa, M. Argaw, and C. Cocozza. 2024. "Effects of Integrated Application of Vermicompost and Inorganic Fertilizers on Selected Soil Characteristics and Productivity of Wheat (*Triticum aestivum* L.) and Faba Bean (*Vicia faba* L.) in Dire and Legedadi Watersheds of Ethiopia." *Applied and Environmental Soil Science* 2024 (1). https://doi.org/10.1155/2024/3163750.

Hammad, H. M., A. Khaliq, F. Abbas, W. Farhad, S. Fahad, M. Aslam, G. M. Shah, W. Nasim, M. Mubeen, and H. F. Bakhat. 2020. "Comparative Effects of Organic and Inorganic Fertilizers on Soil Organic Carbon and Wheat Productivity under Arid Region." *Communications in Soil Science and Plant Analysis* 51 (10): 1406–1422. https://doi.org/10.1080/00103624.2020.1763385.

Helrich, K. 1990. *Method 988.05. Official Methods of Analysis*. 15th ed. Arlington: The Association of Official Analytical Chemists Inc.

Jackson, M. L. 1958. *Soil Chemical Analysis*, 498. Englewood Cliffs, NJ: Prentice-Hall Inc.

Kebede, F., and C. Yamoah. 2009. "Soil Fertility Status and Numass Fertilizer Recommendation of Typic Hapluusterts in the Northern Highlands of Ethiopia." *World Applied Sciences Journal* 6 (11): 1473–1480.

Kraaijvanger, R., and T. Veldkamp. 2015. "Grain Productivity, Fertilizer Response and Nutrient Balance of Farming Systems in Tigray, Ethiopia: A Multi-Perspective View in Relation to Soil Fertility Degradation." *Land Degradation & Development* 26 (7): 701–710. https://doi.org/10.1002/ldr.2330.

Mekuria, W., M. Wondie, T. Amare, A. Wubet, T. Feyisa, and B. Yitaferu. 2018. "Restoration of Degraded Landscapes for Ecosystem Services in North-Western Ethiopia." *Heliyon* 4 (8): e00764. https://doi.org/10.1016/j.heliyon.2018.e00764.

Melak, E., E. Molla, T. Feyisa, W. Sebnie, M. Shitaw, and T. Shiferaw Sida. 2025. "Wheat Yield and Soil Physicochemical Properties through Mineral Nitrogen and Vermicompost Application in Lasta District, North Ethiopia." *Scientific Reports* 15 (1): 32906. https://doi.org/10.1038/s41598-025-16912-7.

Mitiku, H., G. Berhanu, and B. Amare. 2003. "The Status of Soil Fertility in Tigray." In Proceeding of the Policies for Sustainable Land Management in the Highlands of Tigray, Northern Ethiopia. Socio-economic and Policy Research, Working Paper No. 54 ILRI. 28-29 March 2002.

Navneet, S., R. S. Sikarwar, and V. S. Kandalkar. 2019. "Correlation Coefficient Analysis for Yield and Its Components in Sesame (*Sesamum indicum* L.)." *International Journal of Current Microbiology and Applied Sciences* 8 (07): 372–376. https://doi.org/10.20546/ijcmas.2019.807.046.

Njeru, E., S. Grey, and E. Kilawe. 2016. *Eastern Africa Climate-Smartagriculture Scoping Study*. Addis Ababa, Ethiopia, Ethiopia, Kenya and Uganda: FAO.

Okalebo, J. R., K. W. Gathua, and P. L. Woomer. 1993. "Laboratory Methods of Soil and Plant Analysis. A Working Manual. Soil Chemistry Laboratory, the Kenya Agricultural Research Institute, National Agricultural Research Centre, MUGUGA, Kenya." In *The Tropical Soil Biology and Fertility Programme*, 88. Nairobi, Kenya: Regional Office for Science and Technology for Africa, UNESCO.

Olsen, S. R., C. V. Cole, and F. S. Watanabe. 1954. "Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate." USDA Circular No. 939. Washington, DC: US Government Printing Office.

Orkaido, O. 2004. *Effects of Nitrogen and Phosphorus Fertilizers on Yield and Yield Components of Maize (Zea mays L.) on Black Soil of Regede Konso Alemaya University at Konso Special Wereda, Southern Ethiopia.* M.Sc. Thesis Presented to Haramaya University, Ethiopia.

Ouédraogo, E., A. Mando, and N. P. Zombré. 2001. "Use of Compost to Improve Soil Properties and Crop Productivity under Low Input Agricultural System in West Africa." *Agriculture, Ecosystems & Environment* 84 (3): 259–266. https://doi.org/10.1016/S0167-8809(00)00246-2.

Qiang, B., Z. Yan, X. Zhang, M. Cheng, Y. Wu, N. Tang, B. C. Timbang, et al. 2025. "Elevating Crop Productivity and Sustainability: The Role of Organic Fertilizers in Shaping Wheat's Nitrogen Economy and Photosynthetic Response." *European Journal of Agronomy* 170: 127757. https://doi.org/10.1016/j.eja.2025.127757.

Quddus, M. A., R. Ahmed, M. Islam, M. E. Haque, M. A. Islam, A. Alam, M. Z. Rahman, et al. 2025. "Organic and Inorganic Fertilizers Influence the Productivity, Fruit Quality and Nutrient Use Efficiency of Strawberry (*Fragaria x ananassa* Duch.)." *Scientific Reports* 15 (1): 26252. https://doi.org/10.1038/s41598-025-10787-4.

Raju, R. V. S., K. Bokado, B. S. S. Patil, H. S. Devi, and K. Jackson. 2024. "Effect of Organic and Inorganic Sources of Nitrogen on Growth, Yield, Quality and Soil Properties of Wheat (*Triticum aestivum* L.)." *Agricultural Science Digest - A Research Journal* 46 (3): 428–432. https://doi.org/10.18805/ag.D-6010.

Rizwan, A., A. Z. Abid, A. Zahir, S. T. Muhammad, T. Muhammad, and U. Arshad. 2006. "Integrated Use of Recycled Organic Waste and Chemical Fertilizers for Improving Maize Yield." *International Journal of Agriculture & Biology.* http://www.fspublishers.org.

Roba, T. B. 2018. "Review on: The Effect of Mixing Organic and Inorganic Fertilizer on Productivity and Soil Fertility." *OALib* 05 (06): 1–11. https://doi.org/10.4236/oalib.1104618.

Schmitter, P. S., D. Tegegne, A. Adie, F. Baudron, M. Blümmel, and N. Lefore. 2016. "Evaluation of Suitable Water Lifting and on-Farm Water Management Technologies for the Irrigation of Vegetables and Fodder in Lemo District, Ethiopia." International Livestock Research Institute.

Senbeta, A. F., and W. Worku. 2023. "Ethiopia's Wheat Production Pathways to Self-Sufficiency through Land Area Expansion, Irrigation Advance, and Yield Gap Closure." *Heliyon* 9 (10): e20720. https://doi.org/10.1016/j.heliyon.2023.e20720.

Sertsu, S., and T. Bekele. 2000. *Procedures for Soil and Plant Analysis*. Addis Ababa, Ethiopia: Ethiopian Agricultural Research Organization.

Stahr, K. 2010. "The Effect of Compost on Soil Fertility Enhancement and Yield Increment under Smallholder Farming - A Case of Tahtai Maichew District - Tigray region, Ethiopia." Milpitas, CA: PubGenius Inc. https://scispace.com/papers/the-effect-of-compost-on-soil-fertility-enhancement-and-3pudva55ej.

Tegegne, D., M. T. Damtie, and A. Shumye. 2025. "Assessment of Irrigation Performance Trends Using Selected Comparative Indicators over Consecutive Periods: A Case Study of the Koga Irrigation Scheme in the Amhara Region, Ethiopia." *Irrigation and Drainage* 74 (2): 809–819. https://doi.org/10.1002/ird.3021.

Tegegne, D., P. Schmitter, A. Worqlul, W, and N. Lefore. 2025. "Estimating Crop Coefficients for Vegetable Production and Agricultural Water Management under Climate Change in Sub-Humid Tropics." *Frontiers in Water* 7: 1355154. https://doi.org/10.3389/frwa.2025.1355154.

Tegene, B. 1996. "Characteristics and Landscape Relationships of Vertisols and Vertic Luvisols Oftechnology for Enhancing Rice-Wheat. Melbe, Tigray, Ethiopia." *SINET: Ethiopia Journal of Science* 19 (1): 93–115.

Tehulie, N. S. 2020. "The Effect of Organic and Inorganic Fertilizers on Growth and Yield of Bread Wheat (*Triticum aestivum* L.)." *Current Investigations in Agriculture and Current Research* 9 (1). https://doi.org/10.32474/CIACR.2020.09.000302.

Teklu, E., M. Haile, and H. Fitsum. 2004. "Impact of Land Degradation and Soil and Water Conservation Measures in the Northern Ethiopian Highlands." *Mountain Research and Development* 24 (1): 21–28.

Tekulu, K., G. Taye, and D. Assefa. 2020. "Effect of Starter Nitrogen and Phosphorus Fertilizer Rates on Yield and Yield Components, Grain Protein Content of Groundnut (*Arachis hypogaea* L.) and Residual Soil Nitrogen Content in a Semiarid North Ethiopia." *Heliyon* 6 (10): e05101. https://doi.org/10.1016/j.heliyon.2020.e05101.

UNECA. 1964. "Conference on Co-Ordinated Industrialization in West Africa." (1964, Oct. 5 - 15: Bamako, Mali). https://hdl.handle.net/10855/9000.

VSN-International. 2009. *GenStat for Windows*. 12th ed. VSN International.

Walkley, A., and I. A. Black. 1934. "An Examination of the Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method." *Soil Science* 37 (1): 29–38. https://doi.org/10.1097/00010694-193401000-00003.

Wang, J., X. Yang, S. Huang, L. Wu, Z. Cai, and M. Xu. 2024. "Long-Term Combined Application of Organic and Inorganic Fertilizers Increases Crop Yield Sustainability by Improving Soil Fertility in Maize-Wheat Cropping Systems." *Journal of Integrative Agriculture* 24 (1): 290–305. https://doi.org/10.1016/j.jia.2024.07.003.