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Nitrogen Sources Differentially Affect Wheat Varieties' Response under Nitisol Condition

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Abstract: Improving food production among smallholder farmers in the central highlands of Ethiopia poses a significant challenge due to the continuous cultivation of crops without adequate replenishment of nutrients. In the 2019 cropping season, a study was undertaken to assess the effectiveness of vermicompost, nitrogen fertilizer and their combinations in maintaining soil fertility to enhance wheat productivity. The experiment was arranged as a split-split-plot design, with wheat varieties (Wane and Danda'a) as the main plot factor, four vermicompost application rates (0, 2.5, 5 and 7.5 tons per hectare) as sub-plots and four nitrogen fertilizer rates (0, 23, 46 and 69 kilograms per hectare) as sub-sub-plots, each with three replicates. Before planting, the experimental site exhibited unfavorable conditions in terms of soil bulk density, total porosity and pH for wheat cultivation. Furthermore, the soil's fertility status was notably low. The primary impact of vermicompost application significantly improved specific soil physical attributes, while both the main effect and interaction effect of vermicompost and nitrogen fertilizers played a role in altering chemical parameters. The interaction between vermicompost and nitrogen fertilizer positively influenced various yield parameters, including spike length, grains per spike, thousand-grain yield, straw yield and grain yield. Notably, the most favorable combination for enhancing wheat yield was found to be the application of 5 tons per hectare of vermicompost and 46 kilograms per hectare of mineral nitrogen fertilizer. Under these conditions, the experimental yields for the Wane and Danda'a varieties were 5.98 and 5.18 tons per hectare, respectively. In conclusion, to promote wheat productivity, via maintaining soil health, in the study area and similar agro-ecologies, it is recommended that farmers adopt the practice of applying both vermicompost and nitrogen fertilizers in combination.

Key words: Nitrogen Sources · Nitisol · Soil Healthy · Nutrient Interaction · Wheat Productivity

INTRODUCTION

Soil fertility depletion and the resulting low agricultural productivity pose significant challenges in the central highlands of Ethiopia [1]. The gradual decline in soil nutrients, attributed to poor soil management practices, has seriously impeded crop yields in the country. This issue is exacerbated by the intricate relationship between soil properties, landscape characteristics and cultural practices [2]. The primary reliance on synthetic fertilizers for crop production in Ethiopia has raised concerns, as it not only threatens soil fertility and sustainability but also impacts other natural resources. While chemical fertilizers are essential for increasing crop yields, excessive dependence on them can lead to the deterioration of soil physicochemical properties over time, as discussed in various studies [3,4]. Conversely, the use of organic inputs alone falls short of meeting the nutrient demands of improved crop varieties due to their low nutrient content and slow-release characteristics [5, 6].

To address these challenges, integrated soil fertility management, involving the simultaneous use of organic and inorganic fertilizers, emerges as the most effective strategy for not only enhancing soil fertility and crop yields but also enhancing nutrient utilization efficiency [7-9]. However, it's worth noting that the current blanket fertilizer recommendations in Ethiopia do not fully embrace the principles of integrated soil fertility management, which entail the combined use of organic

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sources, chemical fertilizers and improved crop varieties. Therefore, it is imperative to gather sufficient knowledge and evidence to identify the best management alternatives that can address location-specific nutrient challenges and provide accessible and affordable solutions for smallholder farmers. With this in mind, the objective of this paper was to evaluate the response of wheat varieties to nitrogen sources fertilizer under the Nitisol condition.

MATERIALS AND METHODS

Description of the Study Area: The experiment took place at the Holeta Agricultural Research Center, which is situated approximately 29 km away from Addis Ababa. The research center is located in the Welmera district of the West Shewa Zone. The precise coordinates of the center are a latitude range of 9°2' 30" to 9° 3' 19.43" North and a longitude range of 38° 28'15" to 38° 30' 25.43" East. The study area experiences a mono-modal rainfall pattern. The annual average rainfall in the area was recorded at 1067 mm, with variations ranging from 834 mm to 1300 mm. Most of the rainfall (85 percent) occurs during the three summer months (June to August). The average minimum temperature in the area is 6.2°C, while the average maximum temperature is 22.1°C. The mean relative humidity is approximately 58.7%. The area is situated at an altitude of 2,400 meters above sea level. The landscape consists of plateau plains that are moderately elevated and gently sloping. The predominant soil type is Nitisol, which is mostly acidic.

Vermicompost Preparation: Vermicompost was prepared locally using a vermicomposting unit with dimensions of 1x1x1 m^3. Organic materials such as green plants, animal dung, pulse straw and leaves were used as raw materials. The materials were layered as follows: a 20 cm layer of crop residues (60%), followed by a 5-10 cm layer of animal dung (30%) and a 2-4 cm layer of topsoil (10%). Earthworms (Eisenia foetida) were introduced to the composting unit. Chopped castor leaves were added as feeding materials. The materials were turned every 3 days and water was sprinkled to maintain a moisture content of 60-70%. Vermicompost maturity was determined by visual cues, including the formation of a black-brown color and granular structure. Harvesting of vermicompost occurred two months after decomposition, with manual separation of castings from worms. The harvested vermicompost was shade-dried, sieved and analyzed for nutrient contents in a laboratory using standard procedures.

Experimental Design and Treatment Setup: The experiment employed a factorial split-split-plot design with three replications. The main plots involved two wheat varieties: Wane and Danda'a. Sub-plots were used to test different levels of vermicompost (0, 2.5, 5 and 7.5 tons per hectare). Sub-sub-plots were designated for nitrogen fertilizer rates (0, 23, 46 and 69 kg N per hectare). Treatments were randomized within each block. The experimental field was prepared using standard land preparation practices, tractor-mounted disk plowing and disk harrowing. Sowing of wheat varieties took place at the end of June, with 20cm row spacing and 150 kg/ha planting rates. The vermicompost was applied manually and evenly to sub-plots during sowing and thoroughly mixed in the upper 15 cm of soil. The recommended nitrogen (60 kg ha^{-1}) and phosphorous (69 kg ha^{-1}) fertilizer were applied. Other relevant field trial management practices such as weeding and crop protection were uniformly applied with close supervision during the crop growth period.

Soil Sampling and Analysis: Soil samples were taken both before and after planting from the experimental field. Disturbed (using auger) soil samples which were composited by thoroughly mixing and undisturbed (using core) ones were also collected. Before planting, disturbed samples were randomly taken from five different spots across each block from a depth of 0-20 cm to make one composite sample. After harvesting (five months later), soil samples were collected from each plot at a depth of 0 - 20 cm. The collected soil samples were bagged, labeled and submitted to the Holeta Agricultural Research Laboratory. In the laboratory, a sufficient amount of composite soil samples was air dried and ground to pass a 2-mm sieve except for organic carbon and total N in which a 0.5 mm sieve was used. Then, soil samples were analyzed for physicochemical properties following standard laboratory procedures. The pH of the soil was measured from the suspension of 1:2.5 (weight/ volume) soil-to-water ratio using a glass electrode attached to a digital pH meter [10]. Organic carbon content was determined using the Walkley and Black [11] wet digestion method. Total Nitrogen content was determined by the Kjeldahl digestion [12]. Available Phosphorus was extracted using the Bray-II method [13]. The P extracted with this method was measured by spectrophotometer following the procedures described by Murphy and Riley [14]. The exchangeable acidity of the soil was determined by leaching titration with 1N KCl as described by Van Reeuwijk [15]. Cation exchange capacity was determined from the extract using the ammonium acetate method [16]. Vermicompost analysis was made following the standard procedure of soil analysis.

Agronomic Data Collection: The number of days it took for 50% of the spikes to fully emerge after sowing was calculated as "Days to heading." The "Days to maturity" were visually estimated by determining the number of days from sowing to the point when 90% of the plants in a plot reached physiological maturity. Plant height was measured using a meter rod on five pre-tagged plants, starting from the base of the plant and ending at the tip of the spike (excluding the awns). The average height of these five plants was used to calculate the mean plant height. The number of productive tillers per plant was counted by selecting five random pre-tagged plants from the plot. Spike length was measured by randomly selecting five spikes and their lengths were added together and divided by five to obtain the average spike length in centimeters. To determine the thousand-grain weight, 1000 randomly selected grains were weighed in three replicates and the average weight in grams was recorded. For harvesting, the aboveground plant mass from the central 4.14m² areas of each plot was collected when the plants showed clear signs of maturity, such as complete yellowing of leaves and spikes. The collected biological yield was dried in the open air for two weeks to remove moisture and then weighed. The weight was converted to tons per hectare (t ha-1). Grain yield was recorded separately after separating it from the straw yield of each plot. To adjust the grain yield to a standard moisture level, a conversion factor was computed for each treatment using the formula:

Adjusted Grain Yield = Actual Grain Yield * Conversion Factor

$$\text{Conversion factor} = \frac{(100 - \text{actual moisture content})}{(100 - 12.5\%)}$$

Finally, the yield per plot was converted to a per hectare basis and the yield was reported in t ha^{1-}

Data Analysis: All soil and agronomic data underwent statistical analysis of variance using a generalized linear model (GLM) in R statistical software [17]. The significance of the treatments was tested using the agricolae package of R [18]. Means were compared using the lsmean package of R [19] with a Duncan Multiple Range Test (DMRT) set at a 5% level of significance.

RESULTS AND DISCUSSION

Soil Physical-chemical Properties before Planting: An analysis was conducted on surface soil samples (0-20cm depth) taken from multiple replications before planting. The findings revealed that the soil consisted of 68% clay, followed by 20.75% silt and 11.25% sand. According to the USDA Soil Survey Staff [20], the soil textural triangle categorizes the soil as a clay textural class. The measured bulk density at the study site was 1.29 $g.cm^{-3}$, which was close to the critical density for clay soil described by Hazelton and Murphy [21], where root penetration can be severely restricted. The average soil pH at the experimental site was 4.74, indicating strong acidity according to the pH ratings proposed by Tekalign [22]. The preferable pH range for most crops is between 4 and 8 pH, while the ideal pH range for wheat crop growth is 5.5 to 7.4 [23]. Therefore, the soil's pH at the experimental site fell outside the ideal range, suggesting that the availability of essential nutrients for wheat crops was critically affected. The soil organic matter content, total nitrogen and available phosphorus in the study area were 2.09%, 0.11% and 6.32 ppm, respectively. Based on the classification by Tekalign [24] for soil total nitrogen, organic carbon and available phosphorus, the soils in the study area were categorized as low in these nutrients. The pH of vermicompost was 7.6, indicating a moderately alkaline nature. Furthermore, the analysis results showed that the mean organic carbon and total nitrogen contents of vermicompost were 9% and 1.12%, respectively. The available phosphorus content of vermicompost was 16.22 ppm. The average concentrations of exchangeable bases in vermicompost were 12.34, 15.4, 8.2 and 1.32 mol (+) kg^{-1} for potassium, calcium, magnesium and sodium, respectively.

Effects of Integrated Application of Nutrient Source on Wheat Performance

Phenological and Growth Parameters: The analysis of variance showed that the effects of varieties, vermicompost and nitrogen fertilizer significantly ($P \leq 0.05$) influenced days to 50% heading and days to 90% physiological maturity but the two-factor interactions of variety x vermicompost, variety x nitrogen, vermicompost x nitrogen as well as the three-factor interaction of variety x vermicompost x nitrogen did not significantly ($P > 0.05$) influence days to 50% heading and days to 90% physiological maturity (Table 1). Integrated application of vermicompost and nitrogen fertilizer rates decreased days to 50% heading and 90% physiological

Table 1: The main effect of varieties, VC and N fertilizer on phenology and wheat growth parameters

Varieties	50% Days to heading	90%Physiological maturity	Plant (cm)	Productive tiller
Danda'a	79.71[a]	136.92[a]	91.79	3.24
Wane	70.79[b]	122.13[b]	96.71	4.12
$CD_{0.05}$	1.35	2.78	NS	NS
$CV_{(\%)}$	2.5	2	9.8	11.4
Vermicompost				
0	76.00[a]	131[a]	86.22[d]	2.20[d]
2.5	75.71[ab]	129[b]	90.91[c]	3.75[c]
5	74.96[b]	129[b]	93.22[b]	4.90[b]
7.5	74.08[c]	129[b]	95.11[a]	5.60[a]
$CD_{0.05}$	0.85	1.52	2.04	0.36
$CV_{(\%)}$	1.8	1.9	5.5	16.8
Nitrogen				
0	77.67[a]	131.13[a]	85.68[d]	2.20[d]
23	76.42[b]	129.54[ab]	91.66[c]	3.21[c]
45	73.58[c]	128.54[b]	94.62[b]	5.20[b]
69	73.33[c]	128.88[b]	95.75[a]	5.80[a]
$CD_{0.05}$	0.71	1.78	1.72	0.23
$CV_{(\%)}$	1.6	2.4	7.5	8.7

Means followed by the same letter are not significantly different (P = 0.05) according to Duncan's Multiple Range Test, CD = Critical differences = Non-Significant

maturity. Thus, variety Wane took a shorter time (122.13 days) to mature compared to Danda' a variety which took 137 days which might be due to genetic differences of the varieties. Shorter days to physiological maturity (129) were observed in plots treated with vermicompost at the rate of 7.5 t ha^{-1}. This might be because of rapid physiological activities and high plant nutrient availability for the plots treated with high rates of vermicompost as well as N fertilizer as the crop waste a short time on exploring nutrient so that it flowers and matures on time.

The days to 50% heading decreased as the levels of nitrogen increased in both varieties. Accordingly, the Wane variety took a shorter time (70.79 days) to reach 50 % days of heading compared to the Danda variety which took 78 days to flower when both of them were applied with 69 kg N ha^{-1} fertilizer. Variety Danda' a took longer times to reach days to 50% heading when applied with 69 kg N ha^{-1} even though statistically par with 46 kg N ha^{-1} dose. The difference in days to 50% heading between varieties could be a result of a genetic factor. This was in agreement with Bekele [26] who observed phenological differences among varieties. The delay of heading at lower nitrogen and control treatment rates was caused by the longer time it takes the crop to establish, grow and complete the vegetative growth. In agreement with Alemu *et al.* [27] observed prolonged days to heading in control treatment compared to a higher dose of N-fertilizer.

The time it took for both Wane and Danda'a wheat varieties to reach 50% heading decreased as the nitrogen levels increased. Specifically, when both varieties were treated with 69 kg N ha-1 fertilizer, the Wane variety reached 50% heading in a shorter time (70.79 days) compared to the Danda'a variety, which took 78 days to flower. Even when applied with a 46 kg N ha-1 dose, the Danda'a variety took longer to reach 50% heading when compared to the Wane variety. This difference in heading time between the two varieties may be attributed to genetic factors. The delay in heading at lower nitrogen rates and in the control treatment was due to the extended time required for crop establishment, growth and vegetative development. The combination of vermicompost and nitrogen fertilizer had a significant ($P < 0.05$) impact on plant height and productive tiller numbers, but the effects of varieties and interactions between factors did not yield significant ($P > 0.05$) differences in these parameters. Increasing the rates of both vermicompost and nitrogen fertilizer led to increased plant height for both varieties. The study showed that the tallest mean plant height (95.11 cm) was recorded in plots treated with the highest doses of vermicompost and N fertilizer, while the shortest mean plant height (86.22 cm) was recorded in the control plots. This indicates that higher doses of vermicompost and N fertilizer application result in increased plant height compared to the control treatment. The increase in wheat height in response to increasing rates of vermicompost and nitrogen fertilizer may be attributed to nutrient availability, improving vegetative growth. Similarly, Subhan *et al.* [28] and Iqbal *et al.* [29] reported an increase in wheat height with higher nitrogen fertilizer rates.

Table 2: Interaction effect of variety, vermicompost and N- N-fertilizer on spike length

		Spike Length (cm)			
		Nitrogen rate (kg ha^{-1})			
Varieties	Vermicompost (t ha^{-1})	0	23	46	69
Danda'a	0	6.02^{op}	6.25^{no}	6.81^{k-m}	7.16^{h-l}
	2.5	6.30^{no}	6.25^{no}	6.71^{l-n}	7.20^{g-l}
	5	6.60^{mn}	7.00^{j-m}	7.83^{c-e}	7.87^{c-e}
	7.5	7.04^{i-m}	7.19^{g-l}	7.74^{d-f}	8.14^{b-d}
Wane	0	5.76^{p}	7.25^{f-k}	7.53^{e-i}	7.70^{d-h}
	2.5	7.31^{f-j}	7.62^{e-h}	7.41^{e-j}	7.63^{e-h}
	5	7.72^{d-f}	7.89^{c-e}	8.41^{ab}	8.60^{ab}
	7.5	7.57^{e-h}	8.26^{a-c}	8.41^{ab}	8.68^{a}
$CD_{0.05}$			0.43		
$CV_{(\%)}$			3.6		

Means followed by the same letter are not significantly different ($P \geq 0.05$) according to Duncan's Multiple Range Test, CD = Critical Difference

Furthermore, the application of vermicompost and nitrogen fertilizer rates significantly improved the number of productive tillers. The plot receiving the highest dose of vermicompost (7.5 t. ha-1) recorded the maximum number of productive tillers (5.80), while the control plot had the minimum (2.20) number of productive tillers. This improvement in productive tiller numbers may be attributed to the enhancement of soil properties due to vermicompost application, which promotes root growth and distribution, consequently increasing the number of tillers. Kumar [30] and Alemayehu *et al.* [31] reported similar findings on productive tillers due to vermicompost application. Molla *et al.* [32] also observed the highest number of productive tillers in plots receiving the highest vermicompost dose.

Yield and Yield Components: The analysis of variance showed that the effects of vermicompost and nitrogen fertilizer significantly ($P \leq 0.05$) influenced spike length, grain per spike and thousand-grain weight. Likewise, the effect of varieties was significantly ($P \leq 0.05$) affected spike length but did not significantly ($P > 0.05$) affect grain per spike and thousand-grain weight. The two-way interaction of vermicompost x nitrogen had significantly ($P \leq 0.05$) affected spike length, grain per spike and thousand-grain weight. The three-way interaction of variety x vermicompost x nitrogen fertilizer significantly ($P \leq 0.05$) influenced the spike length (Table 2). The two-way interaction of varieties x vermicompost and variety x nitrogen brought nonsignificance ($P > 0.05$) difference in spike length, grain per spike and thousand-grain weight. The three-way interaction of variety x vermicompost x nitrogen did not significantly ($P > 0.05$) affect grain per spike and thousand-grain weight of wheat.

The interaction of nitrogen and vermicompost influenced the spike length of wheat varieties. Variety Wane was observed to produce a relatively longer spike length than the Danda'a variety due to the combined application of vermicompost and nitrogen fertilizer. Increasing the rate of vermicompost and nitrogen fertilizer increased spike length over all the increased levels of both fertilizer sources. Therefore, the longest (8.68 cm) spike length was produced by the Wane variety in response to the combined application of 7.5 t VC ha^{-1} and 69 kg N ha^{-1} rate but statistically par with 7.5 t VC ha^{-1} + 23 kg N ha^{-1}, 5 t VC ha^{-1} + 46 kg N ha^{-1}, 7.5 t VC ha^{-1} + 46 kg N ha^{-1} and 5 t VC ha^{-1} + 69 kg N ha^{-1} treatment combinations.

On the other hand, the shortest (5.76 cm) spike length was also produced by wane variety in response to the application of nil rates of nitrogen and vermicompost. This shows that nitrogen fertilizer and vermicompost had a more pronounced effect on improving wheat spike length. The finding conformed to Tilahun and Tamado [33] who suggested that increasing the rate of nitrogen increased the length of the wheat spike. Similarly, Khan *et al*. [34] found that the application of nitrogen fertilizer increased crop yield parameters. The two-factor interaction of vermicompost and nitrogen fertilizers significantly influenced the number of gains per spike and thousand-grain weight of wheat, Hence, an increase in the rates of vermicompost and nitrogen fertilizer increased the number of gains per spike. Generally, the maximum (57) number of gains per spike was produced at the combination of 5 t VC ha^{-1} +46 kg N ha^{-1} even though statistically par with 5 t VC ha^{-1} + 69 kg N ha^{-1}, 7.5 t VC ha^{-1} + 46 kg N ha^{-1} and 7.5 t VC ha^{-1} + 69 kg N ha^{-1} while the minimum (41) value was produced from the control

Table 3: Interaction effect of vermicompost and N fertilizer on grain per spike

	Number of Grains per spike			
	Nitrogen rate (kgha^{-1})			
Vermicompost (t ha^{-1})	0	23	46	69
0	41^{g}	45^{f}	48^{de}	50^{b-d}
2.5	46^{ef}	45^{f}	48^{cd}	50^{b-d}
5	46^{ef}	51^{bc}	57^{a}	56^{a}
7.5	51^{bc}	51^{b}	56^{a}	56^{a}
CD0.05			2.27	
$CV_{(\%)}$			4.7	

Means followed by the same letter are not significantly different ($P \geq 0.05$) according to Duncan's Multiple Range Test, CD = Critical Difference

Table 4: Interaction effect of vermicompost and nitrogen fertilizer on thousand-grain weight

	Thousand-grain weight (g)			
	Nitrogen (kg ha^{-1})			
Vermicompost (t ha^{-1})	0	23	46	69
0	38.93^{g}	39.53^{fg}	40.17^{d-f}	41.33^{c-e}
2.5	40.33^{d-f}	40.47^{d-f}	40.40^{d-f}	40.33^{d-g}
5	39.80^{ef}	41.67^{bc}	43.67^{a}	42.43^{bc}
7.5	41.02^{c-e}	41.03^{c-e}	42.65^{ab}	43.02^{ab}
CD0.05			1.13	
$CV_{(\%)}$			4.40	

Means followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test, CD = Critical Difference

treatment (Table 3). This improvement in gain per spike with increasing fertilizers might be due to the role of vermicompost and N fertilizer and their synergistic interaction effect to increase grain per spike that contributed to grain production.

The finding agreed with Admasu and Tadesse [35] who observed an improvement in the number of grains per spike because of applying organic manures in combination with chemical fertilizer. Similarly, Rut-Duga [36] reported an increment in thousand-grain weight with a combination of fertilizer source and rate. An increase in the dose of vermicompost and nitrogen fertilizer also increased the thousand-grain weight of wheat varieties with increasing rates of fertilizers. Accordingly, the highest (43.67) thousand-grain weight was obtained at the combined application of 5 t VC ha^{-1} and 46 kg N ha^{-1} but statistically par with 7.5t VC ha^{-1} + 46 kg N ha^{-1} and 7.5t VC ha^{-1} + 69kg N ha^{-1}. On the other hand, the minimum (38.93) thousand-grain weight was recorded from the control plot (Table 4). The increment in thousand-grain weight in response to increased rates of fertilizers may be due to the availability of the optimum amount of nitrogen fertilizer and other nutrients as a result of vermicompost application which had led to high mean thousand-grain weight via improving leaf area and photosynthetic activities, thus improving seed organ development. The finding was in agreement with Edom *et al.* [37] who observed that thousand-grain weight was significantly improved due to the combined application of mineral and organic fertilizers. Similarly, Wassie [38] also reported that the combined application of organic and inorganic fertilizers significantly increased the thousand-grain weight of wheat crops.

The analysis of data indicated that the main effect of vermicompost and nitrogen fertilizer significantly ($P \leq 0.05$) influenced biological and grain yield. The two-factor interactions of vermicompost x nitrogen as well as the three-factor interaction of Variety x vermicompost x nitrogen significantly ($P \leq 0.05$) affected total biomass yield and grain yield. However, the main effect of varieties, the two-factor interaction of variety x vermicompost and variety x nitrogen was non-significant. The interaction of variety x vermicompost x nitrogen fertilizer revealed that biological yields increased with increasing vermicompost and nitrogen fertilizer rates. The highest (14.08 t ha^{-1}) dry biomass yield was obtained from the wane variety applied with 7.5 t VC ha^{-1} + 69 kg N ha^{-1} fertilizers, which exceeded the lowest value (4.01 t ha^{-1}), by about 71.50 percent. This might be due to the improvement in the availability of both native and applied nutrients with better sink and source relationships in the crop, which contributed to better dry matter accumulation in the crop. This increase in above-ground dry biomass at the highest rates of vermicompost and nitrogen fertilizer resulted from improved root growth and distribution, which increased the uptake of nutrients and favored better growth of the crop.

Table 5: Interaction of variety, vermicompost and nitrogen fertilizer on biological yield

		Biological yield (t ha^{-1})			
		Nitrogen rate(kg ha^{-1})			
Varieties	Vermicompost (t ha^{-1})	0	23	46	69
Danda'a	0	4.01^{n}	6.08^{m}	8.27^{ij}	9.35$^{f\text{-}h}$
	2.5	5.79^{m}	7.21^{kl}	9.10$^{g\text{-}i}$	9.60^{fg}
	5	8.21$^{j\text{-}k}$	9.55^{fg}	12.69^{b}	12.51^{b}
	7.5	9.74^{fg}	10.32^{ef}	11.67^{b}	11.80^{cd}
Wane	0	4.47^{n}	6.79^{lm}	8.20$^{i\text{-}k}$	9.87^{fg}
	2.5	6.74^{lm}	8.48$^{h\text{-}j}$	9.03$^{h\text{-}i}$	10.37^{ef}
	5	7.87^{jk}	10.32^{ef}	13.93^{a}	14.02^{a}
	7.5	9.33$^{f\text{-}h}$	10.98^{de}	13.99^{a}	14.08^{a}
CD0.0.5			0.95		
CV $_{(\%)}$			6.1		

Means followed by the same letter within the same are not significantly different ($P \geq 0.05$) according to Duncan's Multiple Range Test, CD = Critical Difference

Likewise, Zaman *et al.* [39] reported the increment in the rate of vermicompost also increased the biological and grain yield of wheat. On the other hand, biomass production in crops depends on photosynthesis. During the growth of the plant, leaves function as sinks, but as plant growth increases, they serve as a source while stems are used as sinks. Thus, leaves are used as the main site of photosynthesis and a source of carbohydrates in plants, which also increases crop biomass production as these organs increase. Evans and Wardlaw [40] elaborated that biomass production is substantially influenced by the photosynthetic activity of the crop. Similarly, Habtamu and Ahadu [41] reported that as plant growth increased, stems and spike length were used as part of photosynthesis, which also helped increase crop biomass production.

The use of vermicompost and nitrogen fertilizer had a significant impact on wheat grain yield, as indicated by a p-value of less than or equal to 0.05. Additionally, the interaction between vermicompost and nitrogen, as well as the interaction between varieties, vermicompost and nitrogen, also had a significant effect on grain yield, suggesting that these factors together influenced wheat production. However, the variety alone and the interactions between varieties and vermicompost or nitrogen did not show a significant impact. The study found that increasing the rates of vermicompost and nitrogen fertilizers consistently led to higher wheat grain yields. The highest yields were observed when 5 tons of vermicompost per hectare were combined with 46 kilograms of nitrogen per hectare, resulting in 5.98 and 51.18 tons per hectare for the Wane and Danda'a varieties, respectively. In contrast, the lowest yields of 1.57 and 1.37 tons per hectare were recorded for the Wane and Danda'a varieties in the control plot. This suggests that combining organic and inorganic fertilizers was more effective than using either type of fertilizer alone. Furthermore, this combined application increased grain yields for both varieties by approximately 73.75 and 73.55 percent compared to the control, indicating a positive response to the integrated approach.

The significant variation in grain yields observed in the study is likely due to synergistic nutrient interactions between the two fertilizer sources. These interactions improved soil physical properties and nutrient availability throughout the crop's growth stages, ultimately enhancing photosynthesis rates and crop health. This, in turn, led to increased plant height, spike length, grain production per spike, thousand-grain weight and above-ground biomass, resulting in higher wheat grain yields. Positive correlations were found between wheat grain yield and spike length, grain production per spike and thousand-grain weight, while soil bulk density showed a negative correlation with grain yield. This indicates that the integrated use of vermicompost and nitrogen fertilizers not only improved soil nutrient status and physical properties but also contributed to enhanced grain yield.

These findings are consistent with previous studies by Zaman *et al*. [43] and Wassie [44], which also reported improved wheat grain yield when vermicompost was combined with chemical fertilizers. Integrated application of vermicompost and nitrogen fertilizer was found to be more effective than using either type of fertilizer alone, aligning with the results of studies by Yousefi and Sadeghi [45] and Obsa and Yeared [46]. Overall, the study highlights the potential to increase wheat yield by integrating organic and mineral fertilizers, which can enhance soil physical fertility and improve wheat yield

Table 6: Interaction of varieties, vermicompost and nitrogen fertilizer on grain yield of wheat

		Grain yield (t ha^{-1}) Nitrogen rate (kg ha^{-1})			
Varieties	Vermicompost (t ha^{-1})	0	23	46	69
Danda'a	0	1.37^{o}	1.82^{n}	2.72^{l}	3.443^{i-k}
	2.5	1.95^{mn}	2.84^{l}	3.47^{i-k}	3.93^{gh}
	5	2.78^{i}	3.74^{h}	5.18^{c}	4.96^{cd}
	7.5	3.21^{k}	4.27^{fg}	4.98^{cd}	4.81^{de}
Wane	0	1.57^{o}	2.17^{m}	2.67^{l}	3.36^{i-k}
	2.5	2.11^{mn}	2.60^{l}	3.67^{i-k}	4.19^{f}
	5	2.84^{l}	3.65^{h-j}	5.98^{a}	5.52^{ab}
	7.5	3.30^{jk}	4.7^{e}	5.74^{ab}	5.54^{b}
CD0.05			0.3		
CV$_{(\%)}$			5.2		

Means followed by the same letter are not significantly different (P $\geq$ 0.05) according to Duncan's Multiple Range Test

Table 7: Interaction effect of vermicompost and nitrogen fertilizer on harvest index

	Harvest Index (%) Nitrogen rate (kg ha^{-1})			
Vermicompost (t ha^{-1})	0	23	46	69
0	29^{e}	31de	33de	35^{cd}
2.5	32de	35^{cd}	39^{ab}	40^{a}
5	34^{cd}	37^{bc}	42^{a}	40^{ab}
7.5	34^{cd}	42^{a}	42^{a}	41^{ab}
CD0.05			3.24	
CV$_{(\%)}$			9.40	

Means followed by the same letter are not significantly different (P $\geq$ 0.05) according to Duncan's Multiple Range Test.

Table 8: Interaction effect of varieties, vermicompost and nitrogen fertilizer on wheat yield

		Grain yield (t ha^{-1}) Nitrogen rate (kg ha^{-1})			
Varieties	Vermicompost (t ha^{-1})	0	23	46	69
Danda'a	0	1.37^{o}	1.82^{n}	2.72^{l}	3.443^{i-k}
	2.5	1.95^{mn}	2.84^{l}	3.47^{i-k}	3.93^{gh}
	5	2.78^{i}	3.74^{h}	5.18^{c}	4.96^{cd}
	7.5	3.21^{k}	4.27^{fg}	4.98^{cd}	4.81^{de}
Wane	0	1.57^{o}	2.17^{m}	2.67^{l}	3.36^{i-k}
	2.5	2.11^{mn}	2.60^{l}	3.67^{i-k}	4.19^{f}
	5	2.84^{l}	3.65^{h-j}	5.98^{a}	5.52^{ab}
	7.5	3.30^{jk}	4.7^{e}	5.74^{ab}	5.54^{b}
CD0.05			0.3		
CV$_{(\%)}$			5.2		

Means followed by the same letter are not significantly different (P $\geq$ 0.05) according to Duncan's Multiple Range Test, Critical Difference

components, ultimately leading to higher grain yields. Additionally, it was noted that wheat varieties responded positively to vermicompost and nitrogen application at medium rates, with no significant improvements in yield beyond this point.

The harvest index was significantly affected by the variety, vermicompost and nitrogen fertilizers, as well as the interaction between vermicompost and nitrogen, while other interactions did not have a significant impact.

The wheat harvest index was increased with increasing the levels of vermicompost and nitrogen fertilizer application. The increase in harvest index in response to an increment in the rates of vermicompost and nitrogen might be attributed to the synergic effect of nutrients in enhancing the growth and yields of wheat. This result was in agreement with Molla *et al*. [47] who reported that the harvest index was significantly increased by the combined application of vermicompost along with inorganic fertilizers. Similarly, Alemayehu *et al.* [48] suggested that the increment in the harvest index of wheat varieties with increased levels of vermicompost and nitrogen fertilizer might be attributed to the greater photo assimilate production and its ultimate partitioning into grains yield than biomass.

The main effect of vermicompost and nitrogen fertilizer significantly ($P \leq 0.05$) influenced the grain yield of wheat. The two-factor interactions of vermicompost x nitrogen as well as the three-factor interaction of varieties x vermicompost x nitrogen significantly ($P \leq 0.05$) affected grain yield (Table 6). However, the main effect of variety, the two-factor interaction of varieties x vermicompost as well as variety x nitrogen was non-significant. Wheat grain yield increased consistently in response to increased rates of vermicompost and nitrogen fertilizer. The highest grain yield of 5.98 and 51.18 t ha^{-1} was obtained respectively from wane and Danda'a varieties both at the combined application of 5 t VC ha^{-1} and 46kg N $ha^{-1,}$ whereas, the lowest grain yield of 1.57 and 1.37 t ha^{-1} was recorded respectively, for Wane and Danda'a varieties from control plots (Table 9). This indicated that the combined use of organic and inorganic fertilizers is more valuable than the sole use of the fertilizers. Moreover, the combined application of 5 t VC ha^{-1} and 46 kg N ha^{-1} increased the grain yield of Wane and Danda'a, respectively, by about 73.75 and 73.55 percent over control. This implied that the two varieties well responded to the integrated application of vermicompost and nitrogen fertilizer from both sources. The high discrepancy between the highest and lowest grain yields in this study seems to be due to synergistic nutrient interaction effects between the two nutrient sources in improving soil physical properties and availing nutrients throughout the developmental stages of the crop to facilitate the rate of photosynthesis brought better crop health and eventually led to an increment in plant height, spike length, grain per spike, thousand-grain weight and above ground biomass consequently increased the final grain yield of wheat crop.

In agreement with the present finding, Molla *et al.* [49] reported that the application of vermicompost with N-fertilizer significantly improved wheat grain yield. Similarly, Zaman *et al.* [50] indicated that the application of vermicompost with chemical fertilizer highly increased wheat grain yield. Integrated application of vermicompost along with N-fertilizer improved wheat grain yield more than the sole application of fertilizers [51, 52]. In general, there is a high potential to increase wheat yield through the integrated application of organic and mineral fertilizers thus enhancing soil physical fertility, which can improve wheat yield components, which directly contributes to an increase in grain yield. Furthermore, the results indicated that the wheat variety responded well to vermicompost and nitrogen application with the medium rate while beyond this rate caused nonsignificant improvements in yield and yield parameters.

CONCLUSIONS AND RECOMMENDATIONS

The initial soil analysis conducted before planting showed that the soil had low levels of certain chemical properties, indicating that it had a limited ability to provide essential nutrients to the wheat crop. Essentially, the soil at the experimental site was not very fertile. This deficiency primarily resulted from the soil's low pH, which severely impacted the availability of vital nutrients for the wheat crop. However, when we introduced a combination of vermicompost and urea fertilizer into the soil, we observed a positive impact on the growth, yield and various yield-related parameters of the wheat crop, such as spike length, grains per spike and thousand-grain yields. Among the different treatments, the highest yield, reaching 5.98 tons per hectare, was achieved by the "wane" variety when we applied a combination of 5 tons of vermicompost per hectare and 46 kilograms of nitrogen per hectare as fertilizer. This approach of integrating vermicompost with nitrogen fertilizers in acidic soils has the potential to improve soil fertility and increase wheat productivity. Consequently, addressing soil fertility issues in acidic conditions through this integrated approach could serve as a viable solution to bridge the yield gap experienced by smallholder farmers, while also mitigating the adverse environmental effects associated with the excessive use of chemical nitrogen fertilizers.

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