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Integrated Use of Fertilizer Source Increase Yield and Economic Benefits of Wheat

Negessa Gadisa and Abdisa Mekonnen

Ethiopian Institute of Agricultural Research,
Holeta Agricultural Research Center P.O. Box 31, Holeta, Ethiopia

Abstract: Maintaining soil fertility and enhancing food production for smallholder is a major challenge in Ethiopia due to nutrient depletion caused by continuous cultivation without adequate external inputs. A study was conducted in 2019 cropping season to investigate the effectiveness of vermicompost, N fertilizer and their combinations in improving wheat productivity and Economic value at Holeta Agricultural Research Center. The experiment was designed in a split- split-plot combination with wheat varieties (Wane and Danda'a) as main plots, four vermicompost rates (0, 2.5, 5 and 7.5 t ha^{-1}) as sub-plot and four N fertilizer rates (0, 23, 46 and 69 kg N ha^{-1}) as sub-sub plot with three replications. The bulk density, total porosity and soil pH of experimental site before planting were in low range of acceptable for wheat crop production. Likewise, fertility status of the study site was also low. The main effect of vermicompost was positively improved selected soil physical. Soil chemical parameters such as organic matter, available phosphorous, available sulfur, exchangeable calcium, Magnesium, potassium and cation exchange capacity were positively influenced. Similarly, synergistic nutrient interaction effect sourced from vermicompost and urea fertilizer brought positive influence on some soil chemical parameters (soil pH and total nitrogen) and yield parameters (spike length, grain per spike, thousand grain yield, straw yield and grain yield). Combined application of vermicompost at 5 t ha^{-1} and mineral nitrogen fertilizer at 46 kg ha^{-1} has better improved yield of wheat crop. The experimental yield of Wane and Danda'a varieties were 5.98 and 5.18 t ha^{-1} at combination of 5 t. ha^{-1} vermicompost and 46kg nitrogen ha^{-1}, respectively. Combined use of variety Wane with 5 t ha^{-1} vermicompost and 46kg N ha^{-1} gave the highest economic benefit of 62186 EB ha^{-1} with the highest marginal rate of return of 6531%. Thus, integrated application of vermicompost and nitrogen fertilizer improved soil fertility and wheat crop yield. Therefore, to alleviate soil fertility constrains through integrated application of vermicompost and nitrogen fertilizer could be one option to increase economic value of wheat and reduce the yield gap seen between smallholder farmers and experimental fields. Hence, in order to sustain wheat crop production, farmers of the study area and similar agro ecologies are advised to make integrated use of vermicompost at (5 t ha^{-1}) and N fertilizer at (46 kg Nha^{-1}) for wane variety.

Key words: Integrated Soil Nutrient・Nitrogen・Nitisol・Vermicompost・Wheat

INTRODUCTION

Soil nutrient depletion as a result of poor soil management have gradually increased and become serious problem to crop productivity in Ethiopia mainly due to association that exists among soil properties, land scape and cultural practice [1, 2]. Crop production depends largely on chemical fertilizers which threaten soil fertility and sustainability. Even though chemical fertilizers are important input to increase crop yield, over reliance would cause decline in soil physico-chemical properties and reduction of crop yields over time [3-8]. On the other hand, the use of organic input alone cannot meet nutrient demands of improved varieties due to their low nutrient content and slow-release process [9, 10].

Integrated soil fertility management in which both organic and inorganic fertilizers used simultaneously is the most effective way to improve soil fertility and to increase yield as compared to the use of either organic or inorganic fertilizers alone [11, 12]. The practice is important not only for improving fertility of soil and increasing yield of crop but also enhance nutrient use

Correspondent Author: Negessa Gadisa, Ethiopian Institute of Agricultural Research,
Holeta Agricultural Research Center P.O. Box 31, Holeta, Ethiopia.

efficiency of varieties [13]. However, the present blanket fertilizer recommendation in Ethiopia did not consider the principles of integrated soil fertility management practices that include the use of organic sources, chemical fertilizers and improved variety together. Thus, it is important to have sufficient knowledge and evidence to find best management alternatives which can solve location-specific nutrient problems and can supply crop nutrient requirement which is accessible and affordable by small holder farmers. Therefore, the objective of this paper was to determine the effect of sole and combined application of vermicompost with N fertilizer on yield and profitability of wheat varieties in the study area.

MATERIALS AND METHODS

Description of the Study Area: The experiment was conducted at Holeta Agricultural Research Center, which is located at a distance of 29 km from Addis Ababa. Holeta Agricultural Research Center is found in Welmera district West Shewa Zone at latitude of 9°2' 30" to 9° 3' 19.43" North and longitude of 38° 28'15" to 38° 30' 25.43" East.

The study area is characterized by mono-modal rainfall pattern. The ten year an average annual rainfall recorded was 1067 mm (834 to 1300 mm). It was high during the three summer months (June to August), which accounts for 85 percent of the annual rainfall. Average minimum and maximum temperatures are 6.2°C and 22.1°C, respectively. The mean relative humidity is 58.7. The area is situated at an altitude of 2,400 m above sea level and characterized by plateau plains, which are moderately elevated and gentle sloping. The area is dominated by Nitisol type which is mostly acidic.

Vermicompost Preparation Procedures: Vermicompost was prepared locally. A vermicomposting unit dimension of 1× 1 × 1 m^3 was set up. It was prepared from organic materials such as green plants, animal dung, pulse straw and leaves. The raw materials were put up in layers in the following sequence according to Suparno *et al.* [14]. A layer of 20 cm crop residues which accounts 60% was spread as bedding materials. A layer of 5-10 cm animal dung which accounts for 30% was scattered over the bedding materials and then a layer of 2-4 cm topsoil which was equal to 10% was spread over cattle dung. Then, species of earthworms (*Eisenia foetida)* were introduced. After inoculation of worms, well chopped castor leaf was spread over as feeding materials subsequently upon decomposition. The materials in the bin were turned every 3 days and sprinkling of water was done to maintain 60-70% moisture content until 90% bio-wastes were decomposed. Maturity of the vermicompost was judged visually by observing the formation of black-brown color and granular structure of the vermicompost at the surface of the bin. Two months later, upon decomposition, the vermicompost was harvested. The harvesting was made by manual separation of castings from worms. The vermicompost obtained was shade dried, sieved and analyzed for nutrient contents using standard procedures in the laboratory.

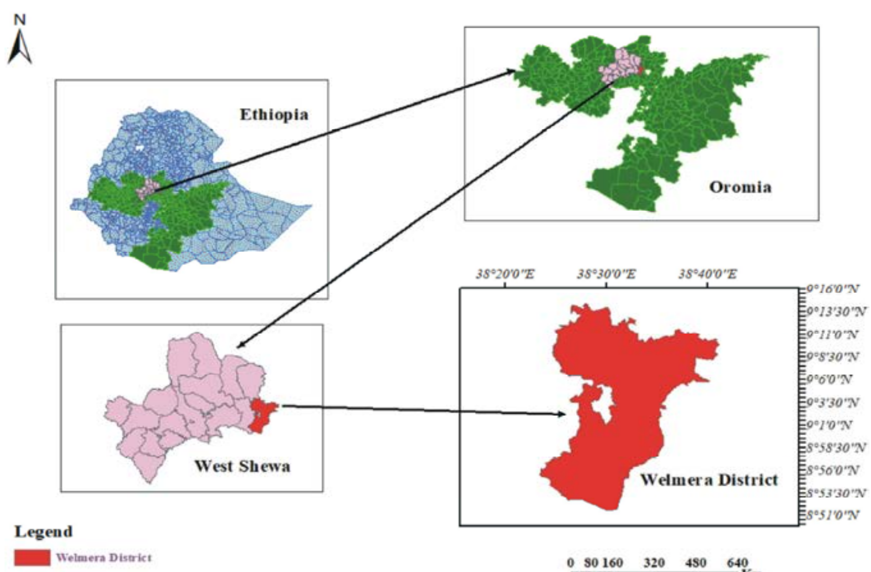

Fig. 1: Map of the Study Area

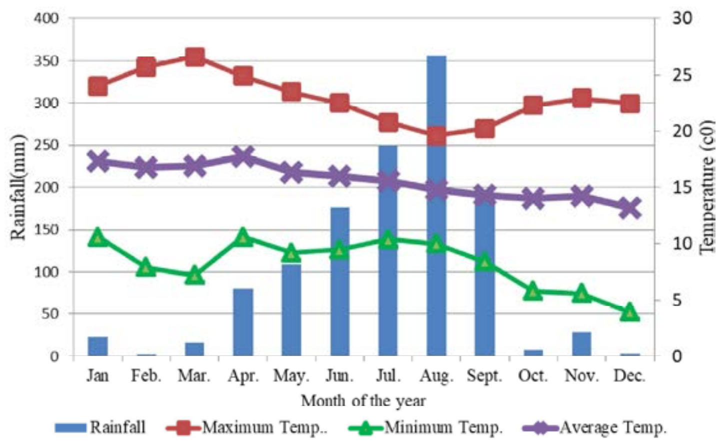

Fig. 2: Total rainfall and mean temperature of the area

Treatments and Experimental Design: The experiment was arranged in a factorial split- split-plot design with three replications. Two wheat varieties (Wane and Danda'a) as main plots, four vermicompost amendment levels (0, 2.5,5 and 7.5 t. ha^{-1}) as sub-plot and four N fertilizer levels (0, 23, 46 and 69 kg N ha^{-1}) as sub-sub-plots were used. Treatments were randomized in every block. The experiment was conducted at the experimental field of Holeta Agricultural Research Center. The experimental site was prepared for sowing using standard land preparation practices of the center; Tractor-mounted disk plowing and disk harrowing was carried out in May 2019. The area of main plot was 9.5 m x 11.5 m, the area of the sub-plot and sub-sub plot was 9.5 m x 2.5 m and 2 m x 2.5 m respectively. The total area of trial site was 771.75 m^2 and the net plot size of the sub-sub plot was 1.8 m * 2.3 m (4.14 m^2). Sowing was taken place at the end of June. At the time of sowing, the experimental plots were finely delineated manually using rakes and fork diggers and the planting rows were made using iron row markers adjusted in 20 cm row spacing. Then, the Main plots were sown with two bread wheat varieties (Wane and Danda'a*)* at the rate of 150 kg ha^{-1}.

The vermicompost were applied manually and evenly to sub-plots during sowing and thoroughly mixed in the upper 15 cm of soil. The recommended Nitrogen (Urea) fertilizer application rate for bread wheat production is 60 kg N ha^{-1}. To minimize losses and increase efficiency, all the levels of N were applied in the row as urea in two applications; half at planting and the other half at mid-tillering during light rainfall to minimize loss of N. The recommended phosphorus fertilizer (69 kg P ha^{-1}) was uniformly applied as triple super phosphate (TSP) to all plots at sowing in a band to the rows. 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. 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 sufficient amount of composite soil samples were air dried and ground to pass a 2-mm sieve except for organic carbon and total N in which 0.5 mm sieve was used. Then, soil samples were analyzed for physicochemical properties following standard laboratory procedures.

Particle size distribution was determined by the hydrometer method [15]. After determining sand, silt and clay separates; the soil was assigned to textural classes using the USDA soil textural triangle [16]. Bulk density was determined using the core method as described by Jamison *et al*. [17]. The pH of the soil was measured from suspension of 1:2.5 (weight/ volume) soil to water ratio using a glass electrode attached to digital pH meter [18]. Organic carbon content was determined using the Walkley and Black [19] wet digestion method. Total Nitrogen content was determined by the Kjeldahl digestion [20]. Available Phosphorus was extracted using Bray-II method [21]. The P extracted with this method was measured by spectrophotometer following the procedures described by Murphy and Riley [22]. Exchangeable acidity of the soil was determined by leaching-titration with 1N KCl as described by Van Reeuwijk [23]. Cation exchange capacity was determined from the extract using ammonium acetate method [24]. Vermicompost analyzed was made following standard procedure of soil analysis.

Agronomic Data Collection

Yield and Yield Attributes: Yield and yield components like spike length, grain per spike, thousand grain weights, biomass and yield were collected. Five spikes were selected randomly and spike length was measured. Figures of all the five spikes were added and the sum was divided by five to get average spike length in centimeter. Grain per spike obtained from the averages of five plants were recorded Thousand grain weight was determined for each plot using electronic seed counter in three replications by weighing 1000 randomly selected grains and their average weight were recorded in grams. Wheat crop was harvested by collecting the above ground plant mass from the central 4.14m^2 area of each plot when the plant showed clear signs of maturity (complete yellowing of leaves and spikes). Total above ground plant biomass (biological yield) obtained was dried up to lose the moisture content, for two weeks, in open air and weighed. Then, the weight was converted into t ha^{-1}. Grain yield was recorded after separating grain from straw yield of each net plot. Then, the grain yield obtained from each plot was adjusted to the standard moisture level by computing the conversion factor for each treatment to get the adjusted yield following Biru [25] procedure. Finally, yield per plot was converted to per hectare basis and the yield was reported in t ha^{-1}.

Data Analysis and Interpretation: All soil and agronomic data were subjected to statistical analysis of variance using a generalized linear model (GLM) in R statistical software version 3.5.3 [26]. Significance of the treatments was tested using the agricolae package of R [27]. The means were compared using the lsmean package of R [29] with Duncan Multiple Range Test (DMRT) set at a 5% level of significance.

Economic Analysis: To evaluate the economic feasibility of chemical and organic fertilizer treatments, economic cost and benefit analysis was done based on the partial budget analysis techniques detailed in (CIMMYT [30]. For the economic analysis, the prevailing market price for inputs during planting time and prevailing market price for outputs (wheat grain and straw yield) during harvesting time was considered. The mean wheat yield for each treatment was averaged. All costs and benefits were calculated on a hectare (ha) basis. The partial budget analysis was conducted. Mean wheat yield was computed as the average yield (kg ha^{-1}) of each treatment minus 10% of the yield (to estimate what can be expected for a farmers' field). Market price for grain of Bread wheat = 16 ETB kg^{-1}, Market price of straw= 1.5 ETB kg^{-1} cost of vermicompost = 3.5 ETBkg^{-1}, Cost of Urea (N-source) fertilizer = 13 ETB kg^{-1}, Labor cost for fertilizer application per persons 50 ETB day^{-1}, Vermicompost transportation and application cost =50 ETB per person.

RESULTS AND DISCUSSION

Soil Physicochemical Properties Before Planting: Selected physico-chemical properties were analyzed for composite surface soil (0-20cm) samples collected from each replication before planting. The results indicated that the soil has 68 % clay followed by 20.75 silt and 11.25% sand and could be categorized as clay textural class on the basis of USDA Soil Survey Staff [31] soil textural triangle. The measured bulk density (1.29 g cm^{-3}) at the study site was close to the critical value density for plant growth at which root penetration is likely to be severely restricted for clay soil as described by Hazelton and Murphy [32].

The mean soil pH of the experimental site was 4.74, which is strongly acidic on the basis of pH ratings proposed by Tekalign [33]. According to Mengel and Kirkby [34], the ideal soil pH for wheat crop growth is 5.5 to 7.4 pH range. Thus, the pH of the experimental soil was out of ideal range of soil pH, which indicates the availability of essential nutrients for wheat crop is critically affected. Soil organic matter, total nitrogen and available phosphorus content of the study area were 2.09 %, 0.11% and 6.32 ppm, respectively. According to the classification of soil total nitrogen, organic carbon and available P suggested by Tekalign [35], the soils of study area were found in low range. The pH of vermicompost was 7.6 which, moderately alkaline. Moreover, the results of the analysis showed the mean organic carbon and total nitrogen contents of vermicompost were 9% and 1.12%, respectively. Similarly; available phosphorus of vermicompost was 16.22 ppm. The average concentrations of the exchangeable bases of vermicompost were 12.34, 15.4, 8.2 and 1.32 cmol (+) kg^{-1}, for potassium, calcium, magnesium and sodium respectively.

Table 1: Interaction of varieties, VC and N-fertilizer on grain yield of wheat

		Grain yield (t ha^{-1})			
		Nitrogen rate (kgha^{-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

Effects of Vermicompost Combination with N-fertilizer on Yield and Yield Attribute of Wheat Varieties: The main effect of vermicompost and nitrogen fertilizer significantly ($P < 0.05$) influenced 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 ($P < 0.05$) affected grain yield (Table 1). 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 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 1). This indicated that combined use of organic and inorganic fertilizer more valuable than sole use of the fertilizers. Moreover, combined application of 5 t VC ha^{-1} and 46 kg N ha^{-1} increased grain yields of Wane and Danda'a respectively by about 73.75 and 73.55 percepts over control. This implied that the two varieties well responded to 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 rate of photosynthesis brought better crop health and eventually led to increment in spike length, grain per spike, thousand grain weight and above ground biomass consequently increased the final grain yield of wheat crop. This can be evidenced from positive correlation (r=0.66, 0.50, 0.46) of wheat grain yield with spike length, grain per spike and thousand grain weight, respectively (Table 1). However, soil bulk density showed a negative correlation (r=-0.49) with grain yield which indicated that integrated application of vermicompost and N fertilizers not only enhanced nutrient status of soil and physical conditions of the topsoil but also contributed to improvement in grain yield of crop.

In agreement with the present finding, Molla *et al.* [36] reported that application of vermicompost with N-fertilizer significantly improved wheat grain yield. Similarly, Zaman *et al.* [37] and Wassie [38] indicated that application of vermicompost with chemical fertilizer highly increased wheat grain yield. Integrated application of vermicompost along with N-fertilizer improved wheat grain yield than sole application of fertilizers [39]. In general, there is high potential to increase wheat yield through integrated application of organic and mineral fertilizers thus can enhance soil physical fertility which can improve wheat yield components which directly contributes to increase in grain yield. Furthermore, the results indicated that wheat variety responded well to vermicompost and nitrogen application with the medium rate while beyond this rate caused non significant improvements in yield and yield parametres.

Effects of Vermicompost and Nitrogen Fertilizer on Economic Feasibility of Wheat Production: The highest net benefit of EB 63216 with highest marginal rate of return 6512 with value to cost ratio of ETB 65.31 per unit of investment was obtained from Wane variety with combination of 5t VC ha^{-1} and 46 kg N ha^{-1}) treatment. However, the minimum net benefits of 24834 were received from application of wane from control plot

Table 2: Correlation among yield and attributing parameters after application of vermicompost with N Fertilizer

Parameters	SL	GPS	TGW	GY	BY
SL	1.00				
GPS	0.47**	1.00			
TGW	0.21*	0.34*	1.00		
GY	0.66**	0.50**	0.46**	1.00	
BY	0.66**	0.50**	0.47**	0.96**	1.00

SL - Spike Length; GPS -Grain Per Spike; TGW-Thousand Grain Weight; GY -Grain Yield, BY - Biological yield; * and ** -significant at 5% and 1%, respectively.

Table 3: Effects of vermicompost and N fertilizer on economic feasibility of wheat production

V	VC	N	Av.gy	ady	av. sy	GFB	TVC	NB	MRR
D	0	0	1372	1235	4672	26770		26770	
D	0	23	1821	1639	5621	34659		34659	
W	0	0	1472	1325	5999	30200	1325	28875D	
W	0	23	2168	1952	6395	40817	2702	38115	671
W	0	46	2671	2404	6331	47954	3904	44050	494
D	0	46	2690	2421	6587	48621	3921	44700	3669
D	0	69	3342	3008	7776	59793	5258	54535	736
W	0	69	3362	3026	6949	58841	5276	53565D	
D	2.5	0	1912	1721	5345	35545	14921	20625D	
W	2.5	0	2110	1899	5970	39334	15099	24235	2026
W	2.5	23	2595	2335	7454	48545	16285	32260	676
D	2.5	23	2707	2436	6440	48641	16386	32255D	
D	2.5	46	3431	3088	6765	59558	17788	41770	679
W	2.5	46	3669	3302	6333	62333	18002	44331	1197
D	2.5	69	3859	3473	7226	66414	18923	47490	343
W	2.5	69	4193	3773	7683	71898	19223	52675	1728
D	5	0	2710	2439	5870	47834	28839	18995D	
W	5	0	2839	2555	6699	50930	28955	21975	2574
D	5	23	3793	3414	6359	64158	30564	33595	722
W	5	23	4080	3672	6961	69188	30822	38367	1850
D	5	46	5179	4661	6779	84751	32561	52190	795
D	5	69	4897	4407	7156	81251	33057	48193D	
W	5	46	5987	5388	6864	96504	33288	63216	6512
W	5	69	5523	4971	7138	90242	33621	56621D	
D	7.5	0	3145	2831	6612	55210	42431	12780D	
W	7.5	0	3303	2973	5796	56258	42573	13685D	
D	7.5	23	4141	3727	7041	70192	44077	26115D	
W	7.5	23	4229	3806	6889	71236	44156	27080D	
D	7.5	46	4913	4422	6953	81176	45522	35655D	
D	7.5	69	4711	4240	7523	79118	46090	33028D	
W	7.5	46	5743	5169	7135	93407	46269	47138	7865
W	7.5	69	5543	4989	7215	90647	46839	43808D	

V=variety, D=Danda'a, W=wane, VC = Vermicompost, N=Nitrogen, av.yld =average yield (t ha^{-1}), ad. yld=adjusted yield (t ha^{-1}), av.sy = average straw yield (t ha^{-1}), GFB = Gross Field Benefit, TVC = Total Variable Cost; NB = Net Benefit, ETB = Ethiopian Birr, Market price wheat grain = 16 ETB kg^{-1}, Market price of straw= 1.5 ETB kg^{-1}, Cost of Urea (N-source) fertilizer = 13 ETB kg^{-1}

(Tables 2-3). Therefore, use of Wane variety when applied with 5t of vermicompost per ha^{-1} and 46 kg N per ha^{-1} is profitable and is recommended for farmers in the study area and other similar agro-ecologies.

CONCLUSION AND RECOMMENDATIONS

Combined use of vermicompost with chemical fertilizers to strong acid soil had increased productivity of wheat. Interaction effect of varieties, vermicompost and N fertilizer were increased wheat grain yield by about 73.44 and 73.84 % over the control, respectively, for Wane and Danda'a varieties which exhibited better improvement than sole applications of maximum rate of vermicompost by about 44.82 and N fertilizer by about 43.81% for the former variety. The maximum yield of Wane and Danda'a varieties were 5.98 and 5.18 t ha^{-1} at combination of 5 VC t. ha^{-1} and 46 N kg ha^{-1} respectively.. Nevertheless, the potential wheat productivity in the area has not yet been exploited. Therefore, alleviating the soil fertility constrains of the study area through integrated application of vermicompost and N fertilizer could be one option to reduce the yield gap seen between smallholder farmers and experimental fields besides reducing adverse environmental impact of mineral N fertilizer.

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