Integrated Organic and Inorganic Fertilizer Management Practices for Improved Maize (*Zea mays* L.) Productivity and Soil Fertility in Pawe District, Northwestern Ethiopia

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Abstract

In Ethiopia, the use of inorganic fertilizer alone and poor land management are the major causes of soil fertility degradation, which later contribute to the decline of crop productivity. Therefore, an experiment was conducted to evaluate the effect of integrated use of vermicompost (VC) and inorganic fertilizer on maize productivity and soil fertility at Pawe district, Northwestern Ethiopia during the 2022 cropping season. It consisted of four treatments: T1= recommended rate of inorganic fertilizer (92 N kg/ha), T2= 50% recommended rate of VC + 50% recommended rate of N, T3= 75% recommended rate of VC + 25% recommended rate of N, and T4= 100% recommended rate of VC (4.7 t/ha) based on N equivalence. The experiment was laid out in a randomized complete block design replicated in eight farmers' field. Both agronomic and soil data were taken following standard procedures and the analysis of variance was performed using statistical software (SAS) version 9.4. The analysis of variance indicated that plant height, biomass yield, straw yield, and grain yield differed significantly among the treatments. The highest grain yield, 4350 kg/ha, was recorded for the combined application of 50% of the recommended rate of inorganic fertilizer + 50% of the recommended rate of VC. This increased grain yield by 54% over the application of the full dose (100%) of the recommended rate of VC. Soil pH, available P, OC, and total N contents significantly increased with the application of VC. Moreover, the application of 50% N fertilizer in combination with 50% recommended rate of VC was found to be economically feasible. Hence it is recommended to be used by maize growing farmers in the study area.

Keywords: Grain yield, maize productivity, nitrogen fertilizer, vermicompost, soil fertility

Introduction

Inappropriate use of inputs is one of the major constraints of crop production in Ethiopia. Improving soil fertility using affordable technologies plays a key role in improving crop productivity in the country (Solomon Endris and Jafar Dawid, 2015; Tolera Abera *et al*., 2018). Integrated use of organic and inorganic fertilizers is one of the viable options for improving crop yields. Recently, some research findings have shown the importance of integrating mineral fertilizers and organic resources in ways that are customized to local conditions to achieve optimum yields, soil nutrient improvement, and efficient fertilizer use (Getachew Agegnehu *et al*., 2012).

Vermicompost is one of the organic fertilizers used by farmers in Pawe district. It is produced through the transformation of organic materials and wastes into finely decomposed organic matter by the combined action of earthworms and microorganisms. It contains a significant amount of both micro and macro plant nutrients and is an eco-friendly and effective amendment for less fertile soils. In addition, it has a low C:N ratio, high porosity, high water-holding capacity, and high microbial activity (Lazcano and Domínguez, 2011). Vermicompost (VC) effectively improves soil fertility and the efficiency of applied fertilizers (Moghimi *et al*., 2018). According to Radzi *et al*. (2017), VC can reduce chemical fertilizer consumption by up to 70%. In addition, research reports suggested that the combined application of half the recommended rate of NPS, with 50% of compost based on N-equivalence can be the best alternative for integrated soil fertility management, instead of applying inorganic fertilizers alone for sustainable crop production (Girma Chala *et al*., 2020).

In Ethiopia, maize is an important food crop widely grown in the different regions, including the Benishangul Gumuz Region (Tsedeke Abate *et al*., 2015). But, nutrient deficiencies due to low level of input uses are among the major constraints of its production (Mulisa Wedajo *et al*., 2021). Consequently, in the northwestern part of the country in general, and in Pawe district in particular, low soil fertility is a well-known problem that limits crop productivity (Musefa Redi *et al*., 2016; EthioSIS, 2019) and the land has been subjected to continuous cultivation using inorganic fertilizers, which led to the buildup of soil chemical degradation and the development of soil acidity (Mohammed Yimam, 2017). However, the most viable approach combining inorganic fertilizers with organic fertilizers such as vermicompost (VC) for maize production has not yet been investigated in the area. Therefore, there is an urgent need to develop an effective nutrient management technology that enhances the nutrient use efficiency of inorganic fertilizers while increasing maize productivity in

the area. The objective of this research was, therefore, to determine the optimum combination of VC and inorganic fertilizer for maize production in Pawe district.

Materials and Methods

Description of the study area

The study was conducted in the 2022 main cropping season on *Nitisols* of Pawe district. The district is located at 11° 7'30'' - 11° 29'30'' N latitude and 36° 14'30'' - 36° 34'30'' E longitude in the Belles River sub-basin of Blue Nile, in the lowlands of Northwest Ethiopia. It is about 570 kilometers northwest of Addis Ababa (Figure 1). The altitude of the study area ranges between 1071 -1158 meters above sea level.

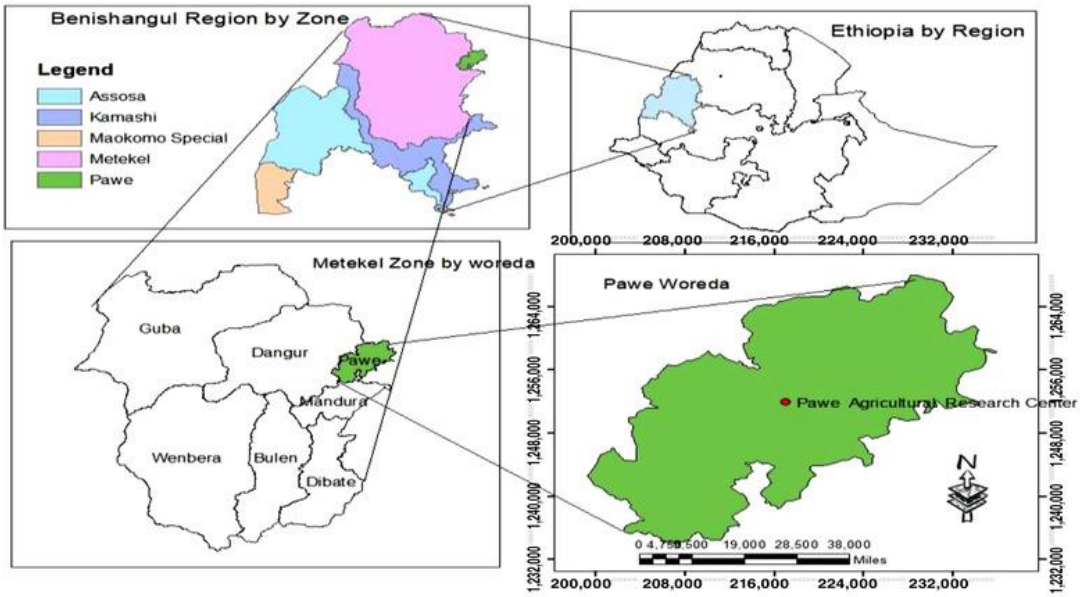


Figure 1. Location map of Pawe district.

According to the meteorological data gathered by Pawe Agricultural Research Center (2017 to 2022), the mean annual minimum and maximum temperatures of the area were 17.1 and 32.6 °C, respectively, and the mean annual rainfall was 1555.9 mm. The area has a uni-modal rainfall pattern

that extends from May to October (Figure 2).

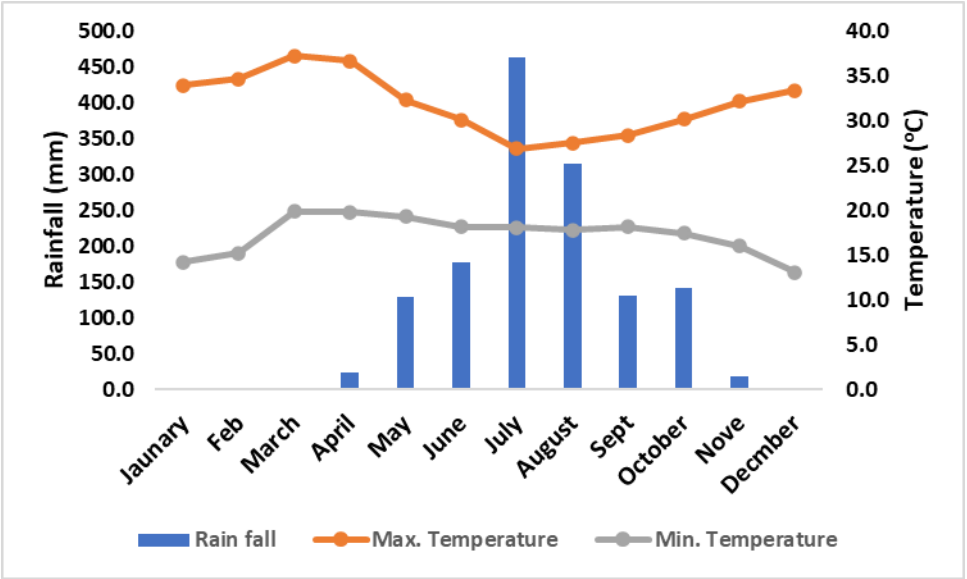


Figure 2. Mean monthly rainfall and mean monthly maximum and minimum temperatures of Pawe district.

Experimental design and procedures

The field experiment was consisted of four treatments; a full dose of recommended rate of inorganic fertilizer (92 N kg/ha) (T1), 50% of recommended rate of VC + 50 % of recommended rate of N (T2), 75% recommended rate of VC + 25% of recommended rate of N (T3) and a full dose of the recommended rate of VC (4.7 t/ha) (T4) based on N equivalence. The experiment was laid out in a randomized complete block design replicated in eight farmers' field. The plot size was 10m x 15m. Improved maize variety, BH546 was considered in the experiment and planted in the first week of June 2022, using 75 cm spacing between rows and 30 cm between plants. Urea fertilizer was applied as a source of N in two splits: once during sowing and the second at the knee height stage. Vermicompost was applied in rows at the time of sowing. The rates of VC fertilizer were calculated based on the recommended rate of N equivalent from the inorganic fertilizer source for the test crop. NPS fertilizer, which farmers use as a P source, was applied uniformly for all treatments, except treatment 4 (100% VC), once at planting. The N amount that is found in the NPS fertilizer was calculated and deducted from the amount of N from urea. All recommended agronomic practices, like plowing and hand weeding, were timely and uniformly applied to all plots.

Data collected

Data on plant height, aboveground biomass yield, grain yield and straw

yield were collected. Grain yield data was adjusted at 12.5% moisture content. All the parameter procedures were collected based on guideline for agronomy and soil fertility data collection in Ethiopia: national standard, EIAR (Dejene Abera *et al*., 2020).

Soil sample collection and analysis

Following the standard soil sampling procedures, representative composite soil samples (with 5-10 sub-samples) were collected at a depth of 0-20 cm from each farmer's field before planting. Similarly, composite soil samples were collected from each treatment after harvesting. Each composite soil sample was subjected to chemical analysis (soil pH, OC, total N, available P, and soil texture). Before laboratory analysis, the samples were air-dried, grounded using a mortar and pestle, and sieved through a 2 mm sieve. For organic carbon (OC) and total nitrogen analysis, soil samples were passed through a 0.5 mm sieve. Soil pH was determined by potentiometric methods at a 1:2.5 soil-to-water ratio as described by Carter (1993). Soil organic carbon content was determined by the Walkley-Black oxidation method (Walkley and Black, 1934). Total nitrogen (TN) content was determined by the Kjeldahl digestion method (Bremner and Mulvaney, 1982). Available P content was determined by the Bray II method (Bray and Kurtz, 1945). Soil texture, the relative proportion of mineral particles of sand, silt, and clay was determined by the hydrometer method (Bouyoucos, 1962).

Soil properties before planting

The soil physicochemical properties of the study sites before planting (Table 1) showed that the experimental site soil was clay and sandy clay soil. Its pH ranged from 5.27 to 6.07, which could be categorized as strongly acidic to slightly acidic soil (Murphy, 1968). The amount of available phosphorus ranged from 1.86 to 5.90 mg kg^{-1}, which is categorized as very low (Bray and Kurtz, 1945). The organic carbon content of the soil ranged from 1.84 to 3.13%, which is grouped as medium (Tekalgn Tadesse, 1991). Its total nitrogen content ranged from 0.11 to 0.16%, which is categorized as medium (Tekalgn Tadesse, 1991).

Table 1: Selected soil physicochemical properties of the experimental field before treatment application.

Farmers Numbers	PH (1:2.5 H_2O)	Av. P (mg kg^{-1})	OC (%)	TN (%)	Texture (%)			
					Clay	Silt	Sand	Class
Farm 1	5.4	1.94	2.47	0.14	46	12	42	Clay
Farm 2	5.4	2.67	3.09	0.16	46	12	42	Clay
Farm 3	5.9	3.88	1.86	0.11	38	8	54	sandy clay
Farm 4	5.4	3.48	3.13	0.14	44	14	42	Clay
Farm 5	5.4	2.51	2.47	0.14	44	10	46	sandy clay
Farm 6	5.3	1.86	2.36	0.15	46	12	42	Clay
Farm 7	5.5	2.26	2.06	0.15	50	10	40	Clay
Farm 8	6.1	5.90	1.84	0.12	38	8	54	sandy clay
Mean	5.6	3.06	2.41	0.14	44	10.75	45.25	sandy clay

Notes: PH=Power of hydrogen, Av.P=Available phosphorus, OC=Organic carbon, TN=Total nitrogen

Statistical analysis

Analysis of variance (ANOVA) was performed using statistical software version 9.4 (SAS, 2014). Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using the least significant difference (LSD) test. Pearson correlation coefficients were also used to assess the significance of the relationship between grain yield and yield components.

Partial budget analysis

Partial budget analysis was carried out to estimate the economic feasibility of each treatment, using the procedure outlined by CIMMYT (1988). The prices of vermicompost, NPS, urea, transport, and maize grain and straw yield were determined through a market survey during the research period. Labor costs (wage rates) for applying vermicompost and inorganic fertilizer were also determined through market surveys. Yield data were adjusted downward by 10%, since it is assumed that farmers using the same technologies would obtain a 10% lower yield than that obtained by researchers (CIMMYT, 1988). The partial budget analysis was employed for the economic analysis of vermicompost and inorganic fertilizer application for each treatment.

Results and Discussion

Effects of vermi-compost and N fertilizer on some selected soil chemical properties after harvest

The results revealed that integrated application of N fertilizer and VC significantly improved total nitrogen, available phosphorus, organic carbon content, and pH of the soil after harvest. Application of 50% N + 50% VC showed better improvement of the soil pH from 5.51 to 5.65, total N from 0.14 to 0.18%, OC from 2.29 to 2.50%, and available phosphorus from

3.06 to 3.63 mg kg^{-1}(Figure 3). However, it was not significant (P>0.05) with the integrated application of 75% VC and 25% inorganic fertilizer. In agreement with these results, it has been reported that application of organic fertilizer significantly improved soil organic carbon from 1.26% to 1.56%, N from 0.14% to 0.23%, and phosphorous from 7.84 mg kg^{-1} to 12.59 mg kg^{-1} (Girma Chala *et al*., 2020). Similarly, Dagne Chimdessa and Gedefa Sori (2020) have reported that integrated application of inorganic fertilizer and VC improved soil physicochemical properties. The excretion of organic acids like citric, glutamic, tartaric, succinic, lactic, oxalic, malic, and fumaric by microbial activities and the slow release of nutrients from VC could be responsible for the post-harvest improvement in the level of some soil nutrients and pH after integrated application of VC and inorganic fertilizer.

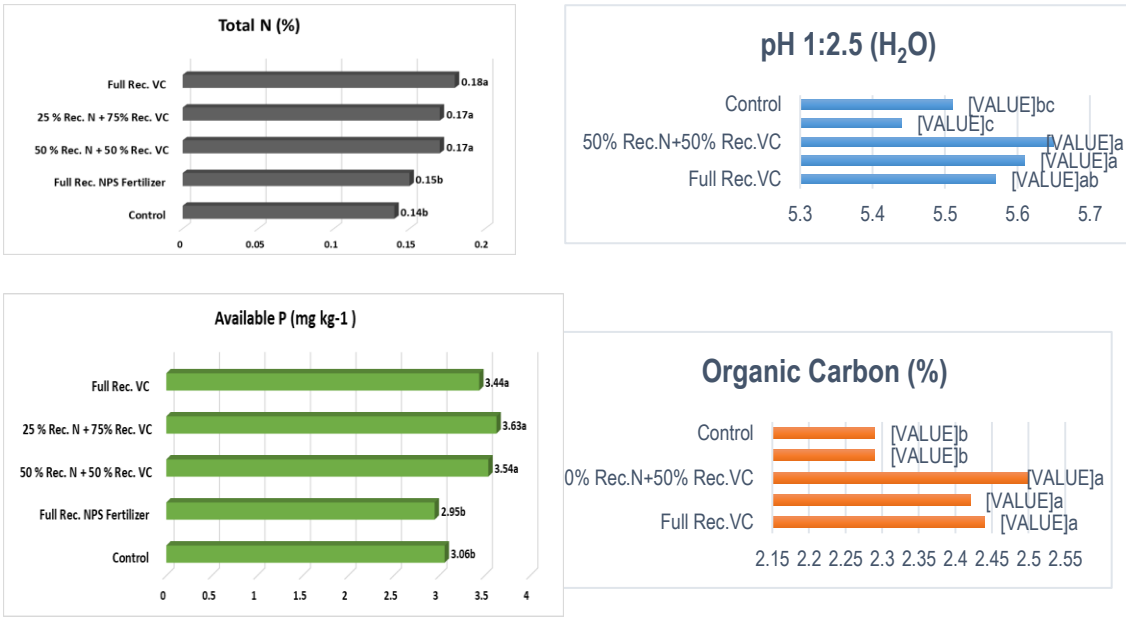


Figure 3. Effect of integrated use of inorganic fertilizer with VC on soil chemical properties after harvesting of the crop

N.B: The control in the figure indicates the soil before planting for the purpose of showing changes in soil property after treatment application.

Effects of vermicompost and N fertilizer on yield and yield components of maize

Plant height

Plant height was significantly ($P < 0.01$) affected by fertilizer treatments. Maximum plant height (249.25 cm) was recorded for the application of 25% of recommended rate of N + 75% of recommended rate of VC, followed by application of 50% recommended N + 50% recommended VC, while the lowest plant height (207.94 cm) was recorded for the application of full dose (100%) of VC (Table 2). Tall plants from the combined applications might be due to the synergistic effects of vermicompost and nitrogen fertilizer in improving the growth of maize. Similar results have also been reported by Mulisa Wedajo *et al*. (2021), and Tolera Abera *et al*. (2019), indicating that plant height of maize was significantly affected by application of sole and integrated use of NPS fertilizer and VC. The shortest plant height recorded from sole application of VC might be associated with gradual release and availability of nutrients from the vermicompost for plant growth (Tolera Abera *et al*., 2019).

Aboveground biomass yield

The analysis of variance showed that the application of vermicompost and N fertilizer significantly ($P<0.001$) affected above ground biomass yield (Table 2). The highest mean aboveground biomass yield (14.60 t/ha) was obtained from application of 50% recommended rate of inorganic fertilizer + 50% of the recommended rate of VC. But it was statistically similar to applications of the recommended rate of N, and combined use of 75% of the recommended rate of VC with 25% of the recommended rate of inorganic N fertilizer. The lowest aboveground biomass yield (9.90 t/ha) was recorded from sole application of vermicompost. Combined application of VC and inorganic N fertilizer at equal proportions increased aboveground biomass yield by 47.5% over application of the full dose of the recommended rate of VC. Similar results have been reported by Mulisa Wedajo *et al*. (2021), and Tolera Abera *et al*. (2019), indicating that above-ground biomass yield of maize was significantly affected by application of sole and integrated use of NPS fertilizer and VC. In their studies, the maximum aboveground biomass yield of maize was recorded from the application of 50% recommended N + 50% VC and the lowest was obtained from the sole application of vermicompost. This indicates that the use of combined nutrient source of fertilizer was advantageous than the use of sole fertilizer sources (Melkamu Hordofa Sigaye et al., 2020). Easy and timely release of available nutrients has contributed to better biomass yield performance (Tolera Abera *et al*., 2019). Biomass yield of maize production depends on the availability

of plant nutrients and the application of fertilizers.

Grain yield

The effect of vermicompost and N fertilizer significantly (P<0.01) affect maize grain yield (Table 2). The highest mean grain yield (4350 kg/ha) was obtained from the combined application of 50% recommended rate of inorganic fertilizer and 50% recommended rate of vermicompost based on N equivalence. This treatment increased grain yield by about 54% over the application of full dose of recommended rate of VC, but it was statistically similar to applications of full dose of recommended rate of N and 75% of recommended rate of VC with 25% recommended rate of inorganic fertilizer. Similar results have been reported by Mulisa Wedajo *et al*. (2021), and Tolera Abera *et al*. (2019), indicating that grain yield of maize was significantly affected by application of sole nutrient source and integrated use of NPS fertilizer and VC. The optimum application of organic and inorganic fertilizers enhances nutrient availability, thereby providing the energy required for seed formation and grain filling (Melkamu Hordofa Sigaye et al., 2020). Vermicompost contains high available nutrients, to provide the best direct and residual effect on the soil and increasing reserves for the succeeding crops (Mulisa Wedajo *et al*., 2021; Nurhidayati *et al*., 2018). The highest grain yield was recorded from the application of vermicompost and NPS fertilizer might be attributed to the improving action of amendments on the physicochemical properties of soil and nutrients status in the soil, which enhances plant growth (Tolera Emamu and Tesfaye Wakgari, 2021).

Straw yield

Straw yield was significantly (P<0.001) influenced by the treatments, where maximum straw yields (10.60, and 10.25 ton ha^{-1}) were recorded for application of 75% of the recommended rate of VC with 25% of recommended rate of inorganic fertilizer, and applications of 50% recommended rate of VC with 50% recommended rate of inorganic fertilizer, respectively. Whereas, the lowest (7.08 t/ha) was recorded for application of full dose of the recommended rate of VC based on N equivalence. (Table 2). The combined application of organic and inorganic fertilizers can significantly affect maize straw yield through the improvements of nutrient release and uptake by the crop. In agreement with the present results, Mulisa Wedajo *et al*. (2021), and Melkamu Hordofa Sigaye et al. (2020), have reported that straw yield of maize was significantly affected by application of sole and integrated use of NPS fertilizer and VC.

Table 2: Effect of VC and inorganic fertilizer rates on growth, yield and yield components of maize.

Treatments	Plant height (cm)	Aboveground biomass yield (t/ha)	Grain yield (kg/ha)	Straw yield (t/ha)
Recommended N	227.29^{bc}	12.95^{a}	4040.3^{a}	8.90^{b}
50% N + 50% VC	243.33^{ab}	14.60^{a}	4350.1^{a}	10.25^{ab}
75% N + 25% VC	249.25^{a}	14.40^{a}	3784.7^{a}	10.60^{a}
100% VC	207.94^{c}	9.90^{b}	2822.0^{b}	7.08^{c}
Mean	231.95	12.96	3749.26	9.21
LSD (0.05)	20.34	1.90	747.83	1.59
CV (%)	8.43	14.10	19.18	16.62

Note: ns= non-significant difference. Means followed by same letter(s) within a column are not significantly different at P = 0.05

Correlation between maize grain yield and yield components

Grain yield was positively and significantly correlated with aboveground biomass yield (r = 0.903, P< 0.05) (Table 3). It also showed positive but non-significant correlations with straw yield (r = 0.812) and plant height (r = 0.774). Above ground biomass yield was very strongly and positively correlated with straw yield (r = 0.984, P<0.01) and plant height (r = 0.971, P<0.05). Similarly, straw yield exhibited an almost perfect positive correlation with plant height (r = 0.998, P<0.001), indicating that increases in straw yield were closely associated with increases in plant height. In agreement with the present results different authors (Temesgen Desalegn *et al*., 2016; Mesfin Kuma *et al*., 2022) have indicated significant associations of grain yield with yield components.

Table 3: Correlation among maize grain yield and yield components for integrated application of vermicompost with inorganic fertilizer

	GY	AGBY	SY	PH
GY	1	0.903*	0.812ns	0.774ns
AGBY		1	0.984**	0.971*
SY			1	0.998***
PH				1

Note: GY = grain yield, AGBY = above-ground biomass yield, SY =straw yield, and PH = plant height.

Partial budget analysis

Results of the partial budget analysis revealed that a maximum net benefit (80,246.67 ETB ha^{-1}) with an acceptable marginal rate of returns (MRR) (517.4%) was recorded for combined application of 50% recommended rate of vermicompost with a 50% recommended dose of inorganic fertilizer (Table 4). This combination generated 6392.46, 34958.27 and 12942.68 ETB ha^{-1} more income than did application of a full dose of recommended rate of nitrogen, full dose of recommended rate of vermicompost, and 25%N + 75% vermicompost, respectively.

From the economic point of view, it was apparent that application of 50%

recommended rate of vermicompost (based on N equivalent) + 50% of the recommended dose of inorganic N fertilizer was more profitable than the rest of the treatment combinations. These findings were in line with Girma Chala *et al*. (2020) who showed that combined application of 50% vermicompost (based on N equivalent) + 50% N and P fertilizers was economically the most feasible alternative on Nitisols of central Ethiopian highlands.

Table 41: Summary of economic analysis of applications of VC and inorganic fertilizer for maize production in Pawe district

Treatment	AGY (Kg ha^{-1})	ASY ton/ha	FBAGY (ETB)	FBASY ETB	GFB ETB	TVC (ETB)	NFB (ETB)	MRR (%)
100% N	3636.27	8.01	83634.21	8010	91644.21	17790.00	73854.21	-
50% N +50% VC	3915.09	9.23	90047.07	9225	99272.07	19025.40	80246.67	517.4
100% VC	2539.80	6.37	58415.40	6372	64787.40	19499.00	45288.40	D
25% N +75% VC	3406.23	9.54	78343.29	9540	87883.29	20579.30	67303.99	D

Note: AGY =adjusted grain yield, AST=adjusted straw yield, FBAGY= financial benefit of Adjusted grain yield, FBASY=financial benefit of adjusted straw yield, GFB =gross financial benefit, TVC = total variable cost, NFB =net financial benefit, MRR =marginal rate of return and D =dominancy

Conclusion and Recommendations

Results of the present study indicated that plant height, aboveground biomass yield, straw yield, and grain yield showed significant differences among treatments. Integrated use of vermicompost and inorganic fertilizer improved maize yield and soil chemical properties. From the economic point of view, it was observed that application of 50% of the recommended rate of inorganic fertilizer (N) plus 50% of the recommended rate of vermicompost based on N equivalence was more profitable than the rest of the treatment combinations. Therefore, it can be concluded that application of 50% inorganic fertilizer in combination with 50% recommended rate of vermicompost was found to be economically the most feasible option, to be recommended for Pawe district and in areas with similar agro-ecologies.

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