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Effect of Combined Application of Organic and Mineral Nitrogen and Phosphorus Fertilizer on Soil Physico-chemical Properties and Grain Yield of Food Barley (*Hordeum vulgare* L.) in Kaffa Zone, South-western Ethiopia

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ABSTRACT

Low soil fertility is one of the major factors limiting the yield of barley in Kaffa Zone, south-western Ethiopia. The problem is more severe in the Zone due to soil erosion and nutrient leaching caused by heavy and continuous rainfall. Thus, field experiment was conducted to assess the effect of combined organic and mineral nitrogen (N) and phosphorus (P) on selected soil physico-chemical properties and on grain yield of food barley in Ghimbo and Adiyo districts, south-western Ethiopia. Fourteen treatments comprising two organic fertilizer rates, *i.e.* 2.5 and 5 t ha^{-1} of Farm Yard Manure (FYM) and Vermicomost (VC) combined with three levels of mineral NP (25, 50 and 75% of recommended rates of NP), 100% recommended rate of inorganic NP (23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}) and no fertilizer application (control) in randomized complete block design on clay soil in Ghimbo and clay loam soil in Adiyo with three replications. Results indicated that the application of FYM in combination with different levels of recommended rates of inorganic N and P significantly improved most of the soil physico-chemical properties and significantly increased the grain yield of food barley over the application of 100% mineral NP alone and the control. The application of 5 t FYM ha^{-1} in combination with 75% recommended rates of inorganic N and P (17.25 kg N ha^{-1} and 34.5 kg P_2O_5 ha^{-1}) was found to be superior and increased soil organic carbon content by 36 and 44.6%, available P by 70.5 and 78.2%, available K by 42.5 and 26.3%, and increased yield of barley by 76.8 and 83.5% in Adiyo and Ghimbo, respectively, over the application of 100% recommended rate of inorganic N and P only. Therefore, it can be concluded and recommended that the application of 5 t FYM ha^{-1} in combination with 75% of the recommended rates of inorganic N and P (17.25 kg N ha^{-1} and 34.5 kg P_2O_5 ha^{-1}) can improve soil fertility and can increase yield of food barley in the study area.

Keywords: Farmyard manure, Nitrogen, Phosphorous, Vermicompost, Ethiopia.

1. INTRODUCTION

Land degradation is the major environmental problem resulting in low and declining agricultural productivity in Ethiopia (Tekalign and Haque, 1987). The average annual soil erosion rate nationwide was estimated at 12 tons ha^{-1}, giving a total annual soil loss of 1,493 million tons (EPA, 2012). As a result, most of Ethiopian soils, especially in the highlands, are low in nutrient content due to erosion, leaching and absence of nutrient recycling (Zeleke et al., 2010). Thus, most of the areas used for cereal crops production, especially for barley, *tef* ([*Eragrostis tef* (Zucc.) Trotter] and wheat (*Triticuum aestivum* L.) are low in soil fertility (Yihenew, 2002).

In Ethiopia, barley covered an area of 1.02 million ha with the average yield of 1.75 tons ha^{-1} and in the study Zone (Kaffa), the crop covered an area of 10,027.76 ha with average yield of 1.32 tons ha^{-1} in the year of 2012/13 (CSA, 2013). However, the potential yield can go up to 6 tons ha^{-1} on experimental plots (Berhane et al., 1996). Barley production is constrained by several problems of which the major ones are use of low yielding local cultivars, improper land preparation, unfavorable weather, disease, pest and weed infestations, low soil fertility etc (Hailu and Van, 1996; Chilot et al., 2002).

Soil fertility depletion owing to high rates of erosion is considered to be the fundamental biophysical root cause for declining per capita food production in Africa (Sanchez and Jama, 2002; Amede and Takele, 2001) including Ethiopia in smallholders' fields (Tesfaye et al., 2011). Nutrient losses (especially N and P) due to low rate of return of biomass to crop fields and inadequate fertilizer application (Gebrekidan, 2003; Zeleke et al., 2010) are identified as major constraints to agricultural production in the Ethiopian farming system including south-western Ethiopia. Thus, external supply of inorganic and organic fertilizer inputs is necessary to increase crop productivity of major food crops in Ethiopia (Wakene et al., 2005).

Organic fertilizer materials, such as farmyard manure (FYM) and vermicompost (VC) improve soil physical properties such as bulk density, porosity, water holding capacity and chemical properties such as CEC, organic carbon, total N, available P, etc (Kale et al., 1992; Satyanarayana et al., 2002). FYM and VC supply all major nutrients (N, P, K, Ca, Mg and S) necessary for plant growth as well as the micronutrients (Fe, Mn, Cu and Zn). Hence, it acts as a mixed complete fertilizer (Mahajan et al., 2008; Dejene and Lemlem, 2012). As livestock rearing is integrated components of livelihood of the farmers in the study area, there is adequate amount of FYM produced by the households.

However, the use of organic fertilizers, such as FYM and VC alone as a substitute to inorganic fertilizers is not sufficient to maintain the present levels of crop productivity of high yielding improved varieties (e.g. Gabulla, Deribe etc) due to their low nutrient content and slow release (Efthimiadou et al., 2010). Therefore, integrated nutrient management in which both organic and inorganic fertilizers are used simultaneously is the most effective method to maintain a healthy and sustainably productive soil (Dejene and Lemlem, 2012). Waseem et al. (2013) concluded from a long-term experiment that addition of FYM and inorganic NP has significantly enhanced grain yield of maize, water use efficiency and soil chemical properties as compared to the use of only inorganic N and P fertilizers. The integrated nutrient management involving judicious use of combined organic and inorganic fertilizer sources is a feasible and productive approach to overcome soil fertility constraints (Efthimiadou et al., 2010).

Therefore, the objective of this study was to assess the effect of combined application of farm yard manure and vermin compost with mineral NP on selected soil physico-chemical properties and on grain yield of food barley in Kaffa Zone, south-western Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the Study Sites

The experiment was conducted in two locations namely at Geri in Ghimbo district and at Angesha in Adiyo district of Kaffa Zone, south-western Ethiopia, in 2013 main cropping season (from July to November). These areas are the potential areas where small cereals including barley are produced within the Zone. The site in Ghimbo district is located at latitude of 8°06´ N, longitude of 36°28´ E and altitude of 2002 meters above sea level (m.a.s.l) while, the site in Adiyo district is located at latitude of 9° 05´ N, longitude of 42° 33´ E, and altitude of 2350 meters above sea level (m.a.s.l).

Table 1. Initial soil physico-chemical characteristics of the experimental sites.

	Ghimbo		***Adiyo***		
Soil parameters	***Value***	***Rating***	***Value***	***Rating***	***References***
Textural class	Clay	-	Clay loam	-	
pH	5.70	Moderately acidic	6.03	Slightly acidic	Hazelton & Murphy (2007)
Organic carbon (%)	1.30	Low	1.52	Low	Hazelton & Murphy (2007). (1999)
Total N (%)	0.08	low	0.11	low	Tekalign (1991)
Available P (mg kg^{-1})	6.70	Low	7.10	Low	Tekalign (1991)
CEC (cmol/kg)	20.15	Medium	18.05	Medium	Landon (1991)

The rainfall pattern of these areas is characterized by bimodal distribution with small rainy season *belg* (March-June) and main rainy seasons *Meher* (July-November). The average annual rainfall was 1120 mm at Geri (Ghimbo) and 1367 mm at Angesha (Adiyo) in 2013 (Wushwush Meteorological Station). The maximum temperature of cropping season varied from 22.1 to 26.6^{0}C in Adiyo and from 25.7 to 28^{0}C in Ghimbo in 2013. Similarly, the minimum temperature varied from 10.0 to 13.1^{0}C in Adiyo and from 13.1 to 14.1^{0}C (October) in Ghimbo.

The soil analysis of the study sites before sowing of the crop revealed that the soil texture of the experimental fields to be clay and clay loam in Ghimbo and Adiyo, respectively, with medium CEC, low organic carbon content, total N, and available P (Table 1).

2.2. Experimental Materials

Different rates of Urea (46% N) and TSP (46% P_2O_5) were used as inorganic N and P sources, respectively, whereas FYM (collected from cow dung and decomposed for six months) and VC (prepared from cow dung, wheat straw and other plant residue by the digestion of earth worms) were used as an organic fertilizer. The organic carbon, N, P, K and moisture contents of the FYM and VC used in the experiment were determined and the result is depicted in Table 2.

Table 2. Organic matter, N, P, K and moisture content of FYM and VC used in the experiment.

Parameter	***FYM***	***Vermicompost***
Organic matter (%)	9.77	5.56
Total N (%)	1.77	1.26
Available P (%)	0.62	0.41
Available K (%)	2.55	2.24
Moisture content (%)	20	14

An improved food barley variety called ‘Gabula’ (Acc. 231222/MS) was used as a test crop. The variety was released in 2007 by Hawassa Agricultural Research Center, Ethiopia, for its high yield and promising agronomic performances in the study areas. The variety matures in 95 days and has an average height of 100 cm. The yield ranges from 2.0-3.5 t ha^{-1} in research fields and 1.5-2.5 t ha^{-1} on farmer’s fields (MoARD, 2007).

2.3. Treatments, Experimental Design and Experimental Procedure

The treatments consisted of a combination of two rates of FYM (2.5 and 5 t ha^{-1}) and two rates of VC (2.5 and 5 t ha^{-1}) with three rates (25%, 50% and 75% of recommended inorganic N and P fertilizers), 100% recommended rate of inorganic N and P fertilizer (i.e., 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}) and no fertilizer (control). Thus, there were 14 treatments: 1). 2.5 t ha^{-1} VC + 25% N and P; 2) 2.5 t ha^{-1} VC + 50% N and P; 3) 2.5 t ha^{-1} VC + 75% N and P; 4) 2.5 t ha^{-1} FYM+25%

N and P; 5) 2.5 t ha^{-1} FYM+50% N and P; 6) 2.5 t ha^{-1} FYM+75% N and P; 7) 5 t ha^{-1} VC + 25% N and P; 8) 5 t ha^{-1} VC + 50% N and P; 9) 5 t ha^{-1} VC + 75% N and P; 10) 5 t ha^{-1} FYM+25% N and P; 11) 5 t ha^{-1} FYM+50% N and P; 12) 5 t ha^{-1} FYM+75% N and P; 13) 100% N and P; and 14) Control (no fertilizer application).

The experiment was laid out in a randomized complete block design with three replications. Each plot had 12 rows of 20 cm (recommended spacing for barley crop) apart each with 3 m length with a gross plot size of 2.4 m × 3 m (7.2 m^2). The first row from each side was considered as border and in each plot; 0.2 m row length at the end of each row was left to avoid the border effect. Therefore, the net plot size was 2.0 m × 2.6 m (5.2 m^2).

The experimental field was ploughed three times and plots were leveled manually. Considering its slow nutrient releasing nature, farmyard manure was applied on dry weight basis three weeks prior to planting of barley and thoroughly mixed with the soil while a well decomposed vermicompost was applied at the time of planting. The barley seeds were sown in rows with an inter row spacing of 20 cm by hand drilling at the seed rate of 120 kg ha^{-1} in the second week of July 2013. All phosphate and half of the N fertilizer rates were applied at planting in the form of TSP and urea, respectively. The remaining half of N fertilizer rate was applied at tillering stage of barley by side dressing. Weeds were controlled manually three times, *i.e.* at early tillering, maximum tillering and booting stages. Harvesting was done manually using hand sickles in the second week of October 2013. The harvested produce was sun-dried for eight days, threshed and winnowed. The grain yield was adjusted to 12.5% moisture content.

2.4. Soil Sampling and Laboratory Analysis

Prior to sowing and after harvest of the crop, disturbed and undisturbed (for bulk density analysis) soil samples were collected from a depth of 0 - 30 cm at five sampling points across the experimental fields in a Zigzag pattern, composited by thoroughly mixing, air dried and submitted to the National Soil Testing Laboratory, Addis Ababa. After harvest of the crop, soil samples were also collected from each plot. The bulk density (Db) of the soil after crop harvest was measured from the undisturbed soil samples collected from each plot using core sampler and determined according to the procedure described in Okalebo et al. (2002). The average soil particle density (PD) (2.65 g cm^{-3}) was used for estimating total soil porosity (Rowell, 1997) as: porosity (%) = [1- (BD/PD)] × 100, where BD is bulk density and PD is particle density. The moisture contents at field capacity (FC) and permanent wilting point (PWP) were measured at -

1/3 and -15 bars, respectively, using pressure plate apparatus and the available water holding capacity (AWHC) was obtained by subtracting PWP from FC (Hillel, 1980). Soil texture was determined using Bouyoucos hydrometer method (Day, 1965).

Selected chemical properties of the soil were determined using standard procedures. The soil pH was determined by 1:2.5 soils: water ratio using a glass electrode attached to a digital pH meter (Page, 1982). The soil organic carbon was determined using Walkley and Black (1954) wet digestion method. Total nitrogen was determined by Kjeldhal digestion method (Jackson, 1973). Available phosphorus was determined by the Olsen method (Olsen et al., 1954) and the cation exchange capacity (CEC) was determined using 1M-neutral ammonium acetate (Jackson, 1973).

2.5. Statistical Analysis

The data were subjected to analysis of variance (GLM procedure) using SAS software version 9.2 (SAS Institute, 2003). Homogeneity of variances was evaluated using the F-test as described by Gomez and Gomez (1984) and as the F-test has shown heterogeneity of the variances of the two locations, separate analysis was done for the two locations. The Fisher’s protected Least Significant Difference (LSD) test at 0.05 probability level was employed to separate treatment means where significant treatment differences existed.

3. RESULTS AND DISCUSSION

3.1. Soil Physical Characteristics

The combined application of organic and inorganic fertilizers had significant ($P<0.01$) effect on the bulk density of the soil both in Adiyo and Ghimbo. The bulk density ranged from 1.21 g cm^{-3} from the application rate of 5 t FYM ha^{-1} in combination with 25% inorganic N and P to 1.61 g cm^{-3}, from the control in Adiyo (Table 3). Similarly, the lowest bulk density (1.20 g cm^{-3}) in Ghimbo was obtained from the application rate of 5 t FYM ha^{-1} in combination with 25 and 50% inorganic N and P and the highest bulk density (1.54 g cm^{-3}) was from the control. Low bulk density in 5 t FYM ha^{-1} applied plots might be due to the availability of organic matter to soil at proper time and proper proportions. This result was in agreement with the findings of Majajah and Dhyan (2001); and Khan et al. (2010) who reported that FYM has advantages in improving the soil organic matter and water holding capacity, with concomitant decrease in bulk density and increasing infiltration rate of water.

Table 3. Bulk density (g cm^{-3}), total porosity (%) and water holding capacity (WHC, %) of the soil after crop harvest as influenced by combined application of organic fertilizer and mineral NP in Kaffa Zone, south-western Ethiopia

Treatment	***Adiyo***			***Ghimbo***		
	Bulk density	***Total porosity***	***WHC***	***Bulk density***	***Total porosity***	***WHC***
2.5 t ha^{-1} VC + 25% NP	1.45^{cd}	45.30^{de}	15.33^{de}	1.34^{ef}	49.43^{b}	18.00^{de}
2.5 t ha^{-1} VC + 50% NP	1.45^{cd}	45.30^{de}	16.66^{d}	1.38^{cd}	47.92^{bc}	17.33^{e}
2.5 t ha^{-1} VC + 75% NP	1.43^{de}	46.00^{cd}	16.00^{d}	1.42^{b}	46.41^{d}	20.66^{b-e}
2.5 tha^{-1} FYM+25% NP	1.47^{bc}	44.52^{ef}	24.33^{c}	1.34^{d}	49.33^{b}	21.66^{bcd}
2.5 tha^{-1} FYM+50% NP	1.41^{e}	46.80^{c}	26.66^{abc}	1.36^{cd}	48.67^{bc}	19.66^{cde}
2.5 tha^{-1} FYM+75% NP	1.45^{cd}	45.30^{de}	25.66^{bc}	1.38^{bc}	47.92^{cd}	17.33^{e}
5 t ha^{-1} VC + 25% NP	1.23^{fg}	53.60^{ab}	29.00^{ab}	1.22^{e}	53.96^{a}	21.33^{bcd}
5 t ha^{-1} VC + 50% NP	1.26^{f}	52.50^{b}	28.00^{abc}	1.22^{e}	53.96^{a}	21.33^{bcd}
5 t ha^{-1} VC + 75% NP	1.23^{fg}	53.60^{ab}	28.66^{ab}	1.23^{e}	53.58^{a}	22.33^{bc}
5 tha^{-1} FYM+25% NP	1.21^{g}	54.30^{a}	29.33^{ab}	1.20^{e}	54.71^{a}	27.00^{a}
5 tha^{-1} FYM+50% NP	1.22^{g}	54.00^{a}	28.00^{abc}	1.20^{e}	54.71^{a}	23.66^{ab}
5 tha^{-1} FYM+75% NP	1.23^{fg}	53.60^{ab}	30.33^{a}	1.21^{e}	54.33^{a}	21.43^{bcd}
100% NP	1.49^{ab}	43.80^{f}	15.00^{de}	1.51^{a}	43.01^{e}	17.00^{e}
Control	1.51^{a}	43.00^{g}	12.00^{e}	1.54^{a}	41.88^{e}	12.00^{f}
Significance	**	**	**	**	**	**
LSD (5%)	0.03	1.24	3.81	0.04	1.62	3.98
CV (%)	1.43	1.53	9.81	1.94	1.94	11.89

Note: Means followed by the same letter within a column are not significantly different from each other at P = 0.05;
FYM = Farmyard Manure, VC = Vermicompost; NP = Nitrogen and Phosphorus;
** Significant at 1% level of significance.

In line with this result, White (1997) also stated that values of bulk density range from < 1 g cm^{-3} for soils high in organic matter to 1.4 g cm^{-3} for well-aggregated soils. Bulk density normally decreases as mineral soils become finer in texture. Therefore, the bulk density values obtained from the combined application of organic and inorganic N and P of most plots in this study were nearly within the range of well- aggregated soils. In view of this, the soils in the study area are not so compact to limit root penetration and restrict movement of water and air. This indicates that the existence of loose soil conditions in the upper 30 cm of the soil depth in all the plots supplied with organic fertilizers, resulted in good structure which might be beneficial for the following cropping season. Similarly, Mbagwu (1992) reported that the decrease in bulk density obtained with manure treated soil was directly related to increased organic matter, which played a significant role in reducing compaction of soils. As source of organic matter, the organic amendments promote the activity of soil fauna and play a major role in the buildup and stabilization of soil structure (Khan et al., 2010).

The combined application of organic and inorganic fertilizers in this study had significant ($P< 0.01$) effect on total porosity and the available water holding capacity of the soil after crop harvest both in Adiyo and Ghimbo (Table 3). The highest total porosity (54.30%) was obtained from the application of 5 t FYM ha^{-1} in combination with 25% inorganic NP in Adiyo and 54.71% was obtained from the application of 5 t FYM ha^{-1} in combination with 25 and 50% inorganic NP in Ghimbo (Table 3). On the other hand, the lowest total porosity, 43%, in Adiyo and 41.88% in Ghimbo were obtained from the control. This increased porosity with the application of FYM may increase root growth leading to accumulation of more organic residues in the soil. This more organic residue in the soil can increase the productivity of the crop as soil organic matter is not only a pool of plant nutrients but also affects soil physical, chemical and biological properties and plays a key role in establishing and maintaining soil fertility (Fageria, 2009).

Similarly, the result of available water holding capacity of the soil after crop harvest ranged from 12% for the control to 30.33% for the combined application of 5 t FYM ha^{-1} with 75% inorganic N and P in Adiyo, and from 12% for the control to 27% for the combined application of 5 t FYM ha^{-1} with 25% inorganic N and P in Ghimbo (Table 4). The result of this study indicated improvement in water holding capacity in response to the addition of organic matter. This could be due to improved soil structure and stable aggregates as well as moisture retention capacity by increasing the total number of storage pores (Bhatacharyya et al., 2008). This clearly indicated that soil organic matter content influences the ability of soils to retain moisture as organic matter not only increases the water holding capacity of the soil but also increases the available water for plant growth (Khan et al., 2010).

3.2. Soil Chemical Characteristics after Crop Harvest

A comparison of soil fertility status before sowing and after harvest of barley revealed that combined application of organic and inorganic NP significantly increased the soil organic carbon content, CEC, available P and available K at both sites (Tables 4 and 5). This indicates improvement in the fertility status of the soil due to an integrated nutrient management (Khan et al., 2010).

Accordingly, the highest soil organic carbon content, 2.76%, in Adiyo and 2.40% in Ghimbo were obtained from the combined application of 5 t ha^{-1} FYM with 75% inorganic N and P (Table 4). The application of 5 t ha^{-1} FYM in combination with 75% inorganic N and P increased the organic carbon content of soil after harvest by 36% and 44.6% in Adiyo and Ghimbo respectively, over the application of 100% recommended rate of N and P alone. The increased organic carbon might be due to higher soil organic matter added from FYM.

These results were consistent with the investigation of Nesgea et al. (2012) who reported that the combined application of FYM with inorganic NP in rice has increased the soil carbon content after harvest by 65% as compared to the application of 100% recommended NP alone (46 kg N ha^{-1} and 65 kg P ha^{-1}). Likewise, Yavarzadeh and Shamsadini (2012) reported that the application of NPK along with FYM and VC in wheat gave significantly higher soil carbon content (5.6%) after harvest over the application of NPK alone. Similarly, Tilahun et al. (2013) indicated that soil organic matter content just after the rice harvest responded significantly to the application of FYM, the highest carbon (8.7%) being recorded for the highest rate (15 t ha^{-1}) of FYM application.

Similarly, the combined application of organic fertilizer with inorganic fertilizer significantly ($P<0.01$) increased the available soil P after crop harvest both in Adiyo and Ghimbo compared to the 100% recommended N and P and the control. The highest available P in Adiyo (14.50 ppm) and in Ghimbo (12.40 ppm) were obtained from the application of 5 t FYM ha^{-1} in combination with 50 and 75% inorganic NP fertilizers, respectively (Table 4). The increase in available P might be attributed to organic manure (FYM), which might have helped in releasing higher amount of P from the soil. In line with this result, Thamaraiselvi et al. (2012) reported that the highest concentration of available soil phosphorus (17.22 ppm) was realized after crop harvest from the combined application of 15 t FYM ha^{-1} and 100 kg P_2O_5 ha^{-1} as compared to control.

Manure also helps in producing intermediate compounds that interact with phosphorus-fixing cations such as aluminium, iron, etc., thereby reducing P adsorption capacity. Similarly, Palm et al. (1997) indicated that organic inputs influence total nutrient availability added to the soil solution by controlling the net mineralization-immobilization patterns. Iyamuremye and Dick (1996) also suggested that organic manures are known to decrease P adsorption/fixation and enhance P availability in P-fixing soils. In agreement with this result, Tolanur and Badanur (2003) attributed the increased available P content of the soil due to release of organic acids during decomposition, which, in turn, helped in releasing P. Generally, the available P status of the soils in the controls at both study sites was very low, even below the critical level (8.5 ppm) (Tekalign, 1991), indicating that the low soil P was among the factors highly limiting the productivity of the soils in the study areas.

There was no significant difference due to the combined application of organic and inorganic fertilizers on the total soil N concentration after crop harvest both in Adiyo and Ghimbo (Table 4). The lack of significant difference could be due to the high mobility of nitrogen which might result in leaching loss due to the heavy rain in the study area. Though there was no significant difference, the combined application of organic and inorganic fertilizers raised the total soil N from initially low concentration (Table 1) to the medium concentration both in Adiyo and Ghimbo.

Table 4. Organic C, available P and total N of soil after crop harvest as influenced by combined application of organic fertilizer and mineral NP in Kaffa Zone, south-western Ethiopia.

Treatment	***Adiyo***			***Ghimbo***		
	Organic C (%)	***Available P (ppm)***	***Total N (%)***	***Organic C (%)***	***Available P (ppm)***	***Total N (%)***
2.5 t ha^{-1} VC + 25% NP	2.01^{d}	10.42^{cdef}	0.21	1.62^{g}	7.30^{bcd}	0.16
2.5 t ha^{-1} VC + 50% NP	2.23^{bcd}	10.30^{def}	0.20	2.08^{d}	7.39^{bcd}	0.18
2.5 t ha^{-1} VC + 75% NP	2.13^{cd}	9.81^{def}	0.20	2.09^{d}	7.53^{bcd}	0.17
2.5 tha^{-1} FYM+25% NP	2.39^{bc}	10.93^{bcde}	0.20	2.07^{d}	8.10^{bcd}	0.18
2.5 tha^{-1} FYM+50% NP	2.43^{bc}	13.59^{abc}	0.21	2.19^{c}	10.15^{ab}	0.18
2.5 tha^{-1} FYM+75% NP	2.50^{ab}	10.93^{bcde}	0.21	2.28^{bc}	9.81^{abc}	0.18
5 t ha^{-1} VC + 25% NP	2.51^{ab}	11.89^{abcd}	0.21	1.92^{ef}	8.13^{bcd}	0.20
5 t ha^{-1} VC + 50% NP	2.31^{bcd}	10.95^{bcde}	0.21	1.83^{f}	8.76^{bcd}	0.18
5 t ha^{-1} VC + 75% NP	2.41^{bc}	10.80^{bcde}	0.20	2.02^{de}	9.02^{bcd}	0.18
5 tha^{-1} FYM+25% NP	2.51^{ab}	14.40^{a}	0.23	2.36^{ab}	12.18^{a}	0.20
5 tha^{-1} FYM+50% NP	2.51^{ab}	14.50^{a}	0.22	2.30^{ab}	12.12^{a}	0.18
5 tha^{-1} FYM+75% NP	2.76^{a}	13.95^{a}	0.21	2.40^{a}	12.40^{a}	0.18
100% NP	2.03^{d}	8.18^{e}	0.20	1.66^{e}	6.96^{cd}	0.16
Control	1.29^{e}	7.63^{f}	0.10	1.07^{h}	6.60^{d}	0.09
Significance	**	**	NS	**	**	NS
LSD (5%)	0.319	2.80	NS	0.102	2.93	NS
CV (%)	8.31	9.34	2.35	3.08	4.61	5.50

Note: Means followed by the same letter within a column are not significantly different from each other at P = 0.05;
FYM = Farmyard Manure, VC = Vermicompos; NP = Nitrogen and Phosphorus;
NS = non-significant; **significant at 1% level of significance.

The integrated application of organic and inorganic fertilizers significantly (P< 0.01) affected CEC of the soil after crop harvest at both sites. Accordingly, the highest CEC of 21.67 $Cmol_c$ kg^{-}

^{1} in Ghimbo and 19.58 $Cmol_c\ kg^{-1}$ in Adiyo were obtained from the combined application of 5 t FYM ha^{-1} with 75% NP while the lowest CEC values were recorded from the control (Table 5). The lowest CEC values observed in the control plots could be attributed to the leaching of bases from the soil due to the high rainfall in the study area, which were not replenished since there was no fertilizer provided to these plots. The application of 100% recommended rate of NP alone had CEC of 17.91 $Cmol_c\ kg^{-1}$ in Adiyo and 20.18 $Cmol_c\ kg^{-1}$ in Ghimbo, which was lower as compared to the application 5 t FYM ha^{-1} with 25, 50 and 75% NP (Table 5). In conformity with this result, Tolanur (2002) reported that cation exchange capacity significantly increased with increased organic manure (15 t FYM ha^{-1}) in conjunction with inorganic fertilizer than the application of inorganic NPK fertilizers alone.

The combined application of organic fertilizers with inorganic NP showed slight increase in soil pH after crop harvest in the study areas with significant ($P< 0.05$) difference in Ghimbo (Table 5). The increased level of application of FYM caused a corresponding increase in soil pH and this could be attributed to the increased microbial activity during the process of decomposition and organic matter formation which could have led to the release of more exchangeable cations or bases that might have increased the soil pH. In line with this result, Ibrawuchi et al. (2007) reported that the application of FYM in soil modified the pH of soil from acidic condition to neutral.

On the other hand, results obtained in Ghimbo revealed that pH of soil after harvest ranged from 5.37 for 100% inorganic NP to pH of 6.01 that was obtained from the combined application of all treatments except the application of 2.5 t VC ha^{-1} in combination with 25% and 50% recommended rate of NP (Table 5). The decline in pH of plots treated with 100% inorganic NP could be attributed to their rapid rates of release of nutrients, which could be immediately used up by plants, leading to poor accumulation of exchangeable bases (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}) that otherwise tend to neutralize soil acidity. The present result was in agreement with the study by Gopinath et al. (2008) who reported decreased soil pH in plots treated with inorganic fertilizers than those treated with organic manures. Likewise, Wokocha and Sopruchi (2010) reported that the application of mineral fertilizer alone reduced the soil pH where it was more pronounced under recommended N dose. Mohd et al. (2007) also described that the oxidation of N fertilizers such as conversion of urea to ammonium ion released H^{+} (potential sources of soil acidity) that decreased the soil pH during the reduction reaction.

Table 5. CEC, pH and available K of soil after crop harvest as influenced by combined application of organic fertilizer and mineral NP in Kaffa Zone, south-western Ethiopia.

Treatment	***CEC ($cmol_c$ kg $^{-1}$ soil)***	***pH (1:2.5 H_2O)***	***Available K (ppm)***	***CEC($cmol_c$ kg $^{-1}$ soil)***	***pH (1:2.5)***	***Available K (ppm)***
2.5 t ha^{-1} VC + 25% NP	18.00^{abcd}	6.01	82.00^{f}	20.6^{abcd}	5.97^{a}	87.00^{ef}
2.5 t ha^{-1} VC + 50% NP	18.80^{abc}	6.01	85.00^{f}	20.15^{de}	5.97^{a}	88.67^{def}
2.5 t ha^{-1} VC + 75% NP	17.37^{cd}	6.01	91.00^{def}	20.44^{bcd}	6.01^{a}	91.00^{def}
2.5 tha^{-1} FYM+25% NP	18.56^{abc}	6.01	97.00^{cde}	20.7^{abcd}	6.01^{a}	96.00^{cde}
2.5 tha^{-1} FYM+50% NP	18.53^{abc}	6.01	104.00^{c}	21.23^{abc}	6.01^{a}	98.00^{bcd}
2.5 tha^{-1} FYM+75% NP	18.27^{abc}	6.01	118.00^{a}	21.22^{abc}	6.01^{a}	105.0^{abc}
5 t ha^{-1} VC + 25% NP	18.55^{abc}	6.01	98.00^{cd}	21.2^{abcd}	6.01^{a}	95.00^{cde}
5 t ha^{-1} VC + 50% NP	18.83^{abc}	6.01	101.00^{cd}	21.35^{ab}	6.01^{a}	98.67^{bcd}
5 t ha^{-1} VC + 75% NP	17.93^{bcd}	6.07	106.00^{bc}	20.6^{abcd}	6.01^{a}	102.0^{abc}
5 tha^{-1} FYM+25% NP	18.98^{ab}	6.08	115.00^{ab}	21.48^{ab}	6.01^{a}	112.00^{a}
5 tha^{-1} FYM+50% NP	19.20^{ab}	6.07	123.33^{a}	21.50^{ab}	6.01^{a}	112.00^{a}
5 tha^{-1} FYM+75% NP	19.58^{a}	6.05	124.00^{a}	21.67^{a}	6.01^{a}	112.00^{a}
100% NP	17.91^{bcd}	6.01	87.00^{ef}	20.18^{cde}	5.37^{c}	88.67^{def}
Control	16.61^{d}	6.01	82.00^{f}	19.23^{e}	5.63^{b}	84.67^{f}
Significance	**	NS	**	**	*	**
LSD (5%)	1.619	NS	10.63	1.06	0.115	10.14
CV (%)	4.99	0.86	5.95	3.03	1.17	5.01

Note: Means followed by the same letter within a column are not significantly different from each other at P = 0.05;
FYM = Farm Yard Manure, VC = Vermicompost; NP = Nitrogen and Phosphorus;
NS = non-significant; **significant at 1% level of significance.

The combined application of organic and inorganic NP has significantly affected the available K of soil after crop harvest at both sites. The highest available K of 124 ppm in Adiyo was obtained from the application of 5 t FYM ha^{-1} in combination with 75% of inorganic NP and in Ghimbo the application of 5 t FYM ha^{-1} in combination with 25, 50 and 75% of inorganic NP fertilizer gave the highest available K (112 ppm) (Table 5). The increase in K availability with the application of FYM might be due to the addition of K from the organic sources and also could be due to higher microbial activities in soil which increased the release of non-exchangeable or fixed-K forms into available forms. In line with this result, Singh et al. (2015) reported significant increase of the available potassium of soil with the addition of FYM.

3.3. Grain Yield of Barley

Grain yield of barley was significantly ($P<0.01$) affected by the combined application of organic and inorganic NP. The highest crop yield improvements of 76.8% and 83.5%, in Adiyo and in Ghimbo, respectively, were obtained from the combined application of 5 t FYM with 75% inorganic NP as compared with the application of 100% recommended rate of NP fertilizers (23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}) followed by the combined application of 5 t FYM with 50% inorganic NP (Table 6).

Table 6. Grain yield (kg ha^{-1}) and percent yield change as influenced by combined application of organic fertilizer and mineral NP in Kaffa Zone, south-western Ethiopia.

Treatment	***Adiyo***		***Ghimbo***	
	Grain yield (kg ha^{-1})	***% change over 100% NP***	***Grain yield (kg ha^{-1})***	***% change over 100% NP***
2.5 t ha^{-1} VC + 25% NP	1796.3	-13.4	1525.7	-19.7
2.5 t ha^{-1} VC + 50% NP	1912.0	-7.8	1756.3	-7.6
2.5 t ha^{-1} VC + 75% NP	2215.0	6.8	1973.3	3.9
2.5 tha^{-1} FYM+25% NP	1860.0	-10.3	1640.3	-13.7
2.5 tha^{-1} FYM+50% NP	2578.3	24.3	2365.7	24.5
2.5 tha^{-1} FYM+75% NP	3132.0	51.0	3026.7	59.3
5 t ha^{-1} VC + 25% NP	2280.3	9.9	2066.0	8.7
5 t ha^{-1} VC + 50% NP	2171.7	4.7	2343.7	23.3
5 t ha^{-1} VC + 75% NP	2568.0	23.8	2050.3	7.9
5 tha^{-1} FYM+25% NP	2755.3	32.8	2573.7	35.4
5 tha^{-1} FYM+50% NP	3349.7	61.5	3293.0	73.3
5 tha^{-1} FYM+75% NP	3668.0	76.8	3486.0	83.5
100% NP	2074.0	0	1900.0	0
Control	1126.0	-45.7	1155.0	-39.2
Significance	**		**	
LSD (0.05)	317.14		320.68	
CV (%)	8.12		8.67	

Note: Means followed by the same letter within a column are not significantly different from each other at P = 0.05;
FYM = Farm Yard Manure, VC = Vermicompost; NP = Nitrogen and Phosphorus;
** Significant at 1% level of significance.

Increase in barley grain yield owing to the combined use of FYM with inorganic NP might be attributed to the release of nutrients to soil slowly for longer duration after decomposition of FYM resulting in better plant growth and yield components. Moreover, it could be due to the addition of both macro and micro nutrients from the FYM, which indicates that even full rate of inorganic NP alone was not adequate for barley production both in Adiyo and Ghimbo. The improvement in soil moisture characteristics resulted from FYM incorporation might have increased the efficiency of mineral NP fertilizer as well. In line with this result, Khalid et al. (2011) reported that the application of 8 t ha^{-1} FYM with 50% recommended rate of inorganic fertilizer has resulted in 88% and 55% yield advantage of wheat over the control and the application of 100% recommended inorganic fertilizer, respectively. Similarly, Abay and Tesfaye (2012) reported that the application of inorganic fertilizers (46/40/50 kg ha^{-1} NPK) with 20 t FYM ha^{-1} gave a better yield of barley than the application of 100% inorganic fertilizers (46/40/50 kg ha^{-1} of NPK) alone.

In general, the increase in grain yield of barley in response to the combined application of the organic fertilizer (FYM) and mineral fertilizers (NP) indicate that soil organic matter is a determinant of soil fertility (Tiessen et al., 1994) in the study area as it is the main storage of carbon, supplies nitrogen, phosphorus, and sulphur to plants, improves soil aggregation, reduces soil sealing and crusting, enhances water infiltration, increases CEC and soil moisture retention capacity (Bationo et al., 2012).

It was also observed from the results of this study that the application of 5 t VC ha^{-1} with 75% inorganic NP fertilizers increased the soil total porosity, but it was not as effective as the application of FYM on increasing yield of barley. This might be due the fact that the VC used for this experiment was slow in releasing nutrients and might help crops that will be grown in the following season.

Though the application of VC did not perform better than FYM with respect to yield of barley in this experiment, the report of Ranva and Singh (2006) indicated that Vermi compost (VC) in wheat resulted in a significant increase in all of the growth parameters and yield attributes than the application of FYM. The low performance of VC in this study could be the low organic matter and NPK content of VC compared with FYM (Table 2). On the other hand, the source from which VC was made may not be as nutritious as FYM as well as the acidic soil of the study area might not be favorable for the decomposition of VC. Similarly, Yavarzadeh and Shamsadini (2012) reported that the effectiveness of VC fertilizer depends on the resources from which it was made and its decomposition and productivity is more efficient in neutral soil pH condition.

4. CONCLUSION

The soil test results after barley harvest revealed significant increase in soil porosity, available water holding capacity, OC, CEC, available P, available K and grain yield of food barley when FYM was applied in combination with inorganic NP than the use of 100% recommended rate of N and P at both locations. Among the treatments, combined application of 5 t FYM with 75% inorganic NP fertilizer was superior. Hence, the use of FYM (5 t ha^{-1}) with 75% recommended rate of N and P (17.25 kg N ha^{-1} and 34.5 kg P_2O_5 ha^{-1}) was found to be appropriate to improve the physico-chemical properties of the soil and to increase the productivity of barley in the study areas as compared to the application of 100% recommended rate of NP (23 kg ha^{-1} and 46 kg P_2O_5 ha^{-1}) alone.

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