

Current and residual effects of compost and inorganic fertilizer on wheat and soil chemical properties

Nigus Demelash, Wondimu Bayu, Sitot Tesfaye, Feras Ziadat, Rolf Sommer
Gonder Agricultural Research Center (GARC), P.O.Box, 1337, Gonder, Ethiopia

Abstract

Restoring soil fertility in smallholder farming systems is essential to sustain crop production. An experiment was conducted in 2011 and 2012 to study the effect of compost and inorganic fertilizer application on soil chemical properties and wheat yield in northwest Ethiopia. Full factorial combinations of four levels of compost (0, 4, 6, 8 t ha⁻¹) and three levels of inorganic fertilizers (0, 17.3, 34.5 kg N/P ha⁻¹) were compared in a randomized complete block design with three replications. In 2012, two sets of trials were conducted: one was the repetition of the 2011 experiment on a new experimental plot and the second was a residual effect study conducted on the experimental plots of 2011. Results showed that in the year of application, applying 6 t compost ha⁻¹ with 34.5/10 kg N/P ha⁻¹ gave the highest significant grain yield. In the residual effect trial, 8 t compost ha⁻¹ with 34.5/10 kg N/P ha⁻¹ gave 271% increase over the control. Grain protein content increased 21 and 16% in the current and residual effect trials, respectively, when 8 t compost ha⁻¹ was applied; it increased 11 and 14% in the current and residual effect trials, respectively, when 34.5/10 kg N/P ha⁻¹ was applied. Under the current and residual effects of 8 t compost ha⁻¹, SOM increased by 108 and 104%; available P by 162 and 173%; exchangeable Ca by 16.7 and 17.4%; and CEC by 15.4 and 17.1%, respectively. Applying 6 t compost ha⁻¹ with 34.5/10 kg N/P ha⁻¹ is economically profitable with 844 % MRR.

Keywords: Soil fertility, Organic matter, Grain protein, Vertisols

Introduction

Poor soil fertility as a result of unsustainable agricultural practices is one of the major threats to agricultural productivity and food security in the smallholder farming systems in Sub Saharan Africa (Sanchez and Leakey 1997). Agricultural productivity and food security in Sub Saharan Africa (SSA) are seriously jeopardized by the steady decline in soil fertility, It is well recognized that soil organic matter plays a major role in soil fertility by affecting physical and chemical properties, and also controlling soil microbial activity by serving as a source of mineralizable carbon (C) and N (Solomon et al. 2002). Thus, productivity losses in many of the SSA countries are often attributed to loss of soil organic carbon and accelerated water depletion resulting from severe soil degradation (Lakew et al. 2000). Complete residue removal for fodder and fuel, and intensive and excessive tillage have depleted soil organic C stocks which have led to the deterioration of soil fertility and soil water storage capacity, resulting in frequent crop failures. Degraded soils commonly reduce payoffs to agricultural investment as they rarely respond to external inputs, such as mineral fertilizers, and hence reduce the fertilizer use efficiency and return on investment (Tilahun, 2003). Such soils also have very poor water holding capacity, partly because of low soil organic matter content, which in turn reduce fertilizer use efficiency (Tilahun, 2003). Overexploitation of land resources without returning the basic nutrients to the soil is an important factor that contributes most to poor productivity (Bationo et al. 2007).

In the highlands of Ethiopia in general, and the Amhara region in particular declining soil fertility is also immensely constraining to agricultural productivity (Lakew et al. 2000). Even though the farming system in the highlands of Amhara region is a mixed crop–livestock system, nutrient flows between the two system’s components are predominantly one way, with feeding of crop residues to livestock but little or no dung and residue being returned to the soil. Estimates of soil nutrient loss in Ethiopia between 1982 and 1984 show a net removal of 41 kg N ha⁻¹ from agricultural land, and losses for the year 2000 were projected to reach 47 kg N ha⁻¹ (Stoorvogel et al. 1993).

Currently, the situation would be worsened with the ongoing intensive cultivation without due regard to restoring soil organic matter content. Therefore, if agricultural productivity in the smallholder farming is to be improved and food security granted, emphasis should be given to

replenishing the soil fertility. On the other hand, although substantial crop yields can be achieved through applying inorganic fertilizers, most smallholder farmers in the Amhara region rarely use them because of high cost and low and variable returns. These soils can no longer be productive with the existing fertility status and if the trend of low inorganic fertilizer use continues, alternative soil fertility management strategies need to be sought. Therefore, an integrated nutrient management approach which acknowledges the need for both organic and inorganic mineral inputs is promoted due to positive interactions and complementarities between them (Abedi et al. 2010). Thus, adopting this strategy should increase crop productivity, prevent soil degradation, enhance carbon storage in the soil and also reduce emissions from nitrogen fertilizer use and thereby help meet future food supply needs. Compost has strong carryover effect, however, the short term benefits of infrequent application to yield and soil qualities in Vertisols have not been evaluated in the watershed. This study was, therefore, conducted at on-farm to evaluate the current and residual effects of different levels of compost and inorganic fertilizer application on wheat grain yield and chemical properties of the soil in the Gumara-Maksegnit watershed.

Materials and methods

Description of the study area

The study was conducted on a farmers' field in the Gumara-Maksegnit watershed in northwest Ethiopia. The watershed is located between 12° 23' 53" to 12° 30' 49" latitude and 37° 33' 39" to 37° 37' 14" longitude and an altitude of 1953 m above sea level. The soil at the experimental site is a Vertisols. The long term average annual rainfall is about 1052 mm. The mean minimum and maximum temperatures of the area are 13.3 °C and 28.5 °C, respectively (NMSA, 2009). The soil had a clay texture with 53% clay, 19% silt and 28% sand contents. The 0–40 cm horizon has on average a pH of 7.5 (1:2.5 in water), 3.96% organic matter, 6.4 ppm available (Olsen) P, 2.16 cmol⁽⁺⁾ kg⁻¹ K, 38.31 cmol⁽⁺⁾ kg⁻¹ Ca, 12.09 cmol⁽⁺⁾ kg⁻¹ Mg, 0.38 cmol⁽⁺⁾ kg⁻¹Na, and CEC of 58.40 cmol⁽⁺⁾ kg⁻¹.

Experimental design and procedures

Treatments comprised factorial combinations of four levels of compost (0, 4, 6, and 8 t ha⁻¹ on dry weight basis) and three levels of nitrogen (N) and phosphorus (P) fertilizer combinations [0/0, 17.3/11.5, 34.5/23 kg N/P₂O₅ ha⁻¹ which represented 0%, 25%, and 50% of the recommended N (69 N kg ha⁻¹) and P (46 P₂O₅ kg ha⁻¹) fertilizer rates, respectively]. The experimental design was randomized complete block with three replications. The study was conducted in 2011 and 2012. In 2012, the residual effect of treatments was studied on the 2011 experimental plots. Compost was applied on dry weight basis, spread evenly, and incorporated into the soil two weeks before planting. The chemical properties of the compost used for the study are presented in Table 1. Urea and di-ammonium phosphate (DAP) were used as inorganic fertilizer sources. Half of the urea and all the DAP were applied in rows at planting and incorporated into the soil. The remainder of the urea was side dressed at tillering. Bread wheat var. Kubsa in 2011 and var. TAY in 2012 were planted in rows at the seed rate of 125 kg ha⁻¹. Planting was made on broad bed and furrows (BBF) to facilitate water drainage. Gross and net plot sizes were 6 m x 6 m and 5 m x 5 m, respectively in 2011. Weeds were removed manually as needed. No insecticide or fungicide was applied as there was no serious incidence of insect pests or diseases.

Table 1. Chemical properties of the compost used for the study.

Chemical properties	Values
pH	6.46
Available P (ppm)	47.73
Organic matter (%)	5.74
CEC (cmol ⁽⁺⁾ kg ⁻¹)	105.0
Exchangeable Ca (cmol ⁽⁺⁾ kg ⁻¹)	50.29
Exchangeable Mg (cmol ⁽⁺⁾ kg ⁻¹)	14.63
Exchangeable K (cmol ⁽⁺⁾ kg ⁻¹)	1.2
Exchangeable Na (cmol ⁽⁺⁾ kg ⁻¹)	0.83

Prior to planting, composite surface (0–40 cm) soil samples were collected from five points across the experimental field and analyzed for soil chemical properties. Composite soil samples from the 0–25 cm depth at three points were collected from each plot 15 days after compost application and the composite sample analyzed for soil chemical properties. Similarly, for the residual effect study, soil samples from 0–25 cm depth were collected from three points at each

plot just before planting and analyzed for soil chemical contents. Soil samples were mixed, homogenized, air dried in shade, ground and passed through a 2 mm sieve, and analyzed for total N, available P, pH, organic carbon, exchangeable cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) and CEC. Soil texture was determined using Bouyoucos hydrometer method (Tisdale et al. 1993). Available P was extracted with sodium bicarbonate solution at pH 8.5 following the procedure described by Olsen et al. (1954). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method as described by Jackson (1958). Soil pH was measured potentiometrically in the supernatant suspension of a 1:2.5 soil:water mixture using a pH meter according to method outlined by Sahlemedhin and Taye (2000). Organic carbon was determined following the Walkley and Black wet oxidation method as described by Jackson (1958). The soil CEC was determined at pH 7 after displacement of the cations by using 1 N ammonium acetate; thereafter, the ammonium was estimated titrimetrically by distillation of ammonium that was displaced by sodium following the procedure of Sahlemedhin and Taye (2000). Total exchangeable bases were determined after leaching the soils with ammonium acetate; Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer and K^+ and Na^+ were analyzed flame photometrically following the procedure of Sahlemedhin and Taye (2000).

Data on grain and straw yields, grain protein content and soil chemical properties were collected. Grain protein content was determined using near infrared reflectance spectroscopy (NIRS). Analyses of variance (ANOVA) for all data were performed using the SAS statistical program (SAS V9.0, SAS Institute Inc., Cary, NC, USA). Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using least significant difference (LSD). Economic analysis was performed following the CIMMYT partial budget methodology (CIMMYT 1988). Average wheat grain price of US\$0.45 kg^{-1} and straw price of US\$1.05 t^{-1} were considered for the analysis. The prices of DAP, urea and compost were US\$0.78 kg^{-1} , US\$0.65 kg^{-1} , and US\$14.47 t^{-1} , respectively. To apply 4, 6, and 8 t compost ha^{-1} , two, three and four man-days, respectively were needed. The labour cost for compost application was US\$1.58 per man-day. Following CIMMYT's partial budget analysis methodology, total variable costs (TVC), gross benefit and net benefit were calculated. Total variable cost was calculated as the sum of cost of urea, cost of DAP, cost of compost and cost of labor to apply compost. Net benefit was calculated as the difference between gross benefit and the TVC. Grain and straw yields were adjusted downwards by 10% assuming that

farmers will obtain yields 10% lower than obtained by researchers. Then treatments were listed in order of increasing total costs that vary and dominance analysis was performed where dominated treatments were eliminated and the marginal rate of return (MRR) calculated for the remaining treatments. A treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated. A treatment which is non-dominated and having a MRR of greater or equal to 100% and the highest net benefit is considered to be economically profitable.

Results

Grain and straw yield

Both in the current and residual effects grain yield was significantly affected by the direct and the interaction effect of the combined use of compost and inorganic fertilizers (Table 2).

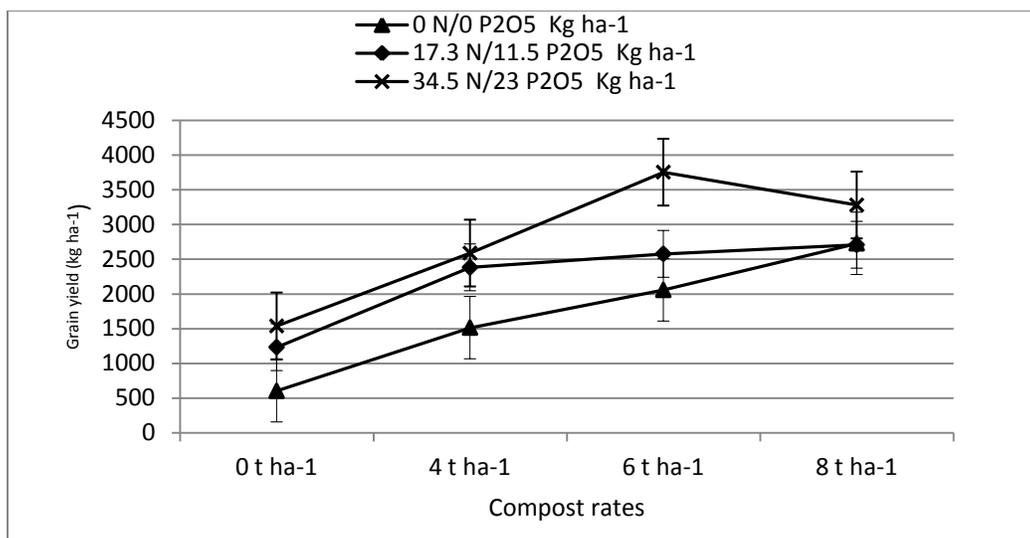
Table 2. Analysis of variance for the effect of compost and inorganic fertilizers on the grain and straw yields and grain protein content of bread wheat in Gumara-Maksegnit watershed

Source of variation	df	Current			Residual		
		Grain yield	Straw yield	GPC	Grain yield	Straw yield	GPC
Compost (C)	3	1276765.05**	4760653.44**	8.92**	1201952.6**	2503855.4**	8.3**
Inorganic fertilizer (F)	2	3872445.98**	7201779.07**	6.04**	3084720.2**	5391588.4**	7.6**
C x F	6	2434768.83**	1181063.74ns	0.63ns	67796.1**	1097806.4.74ns	0.63ns
Error	24	42637.71	980580.57	0.42	42131.7	334585.1	0.48

** and ns denote significant difference at $P \leq 0.01$ and non-significant difference, respectively. GPC = Grain protein content.

In the current effect, the highest significant grain yield was obtained applying 6 t compost ha⁻¹ with 34.5–23 kg N–P₂O₅ ha⁻¹ followed by applying 8 t compost ha⁻¹ with 34.5–23 kg N–P₂O₅ ha⁻¹ (Fig. 1). Applying compost alone also has significantly increased grain yield with a yield benefit ranging from 151 to 351 %. Across all the N–P levels grain yield has significantly increased with an increase in the compost rate. In the residual effect, the highest significant grain yield was obtained from 8 t compost ha⁻¹ with 34.5–23 kg N–P₂O₅ ha⁻¹ applied in the preceding season (Fig. 1).

a)



b)

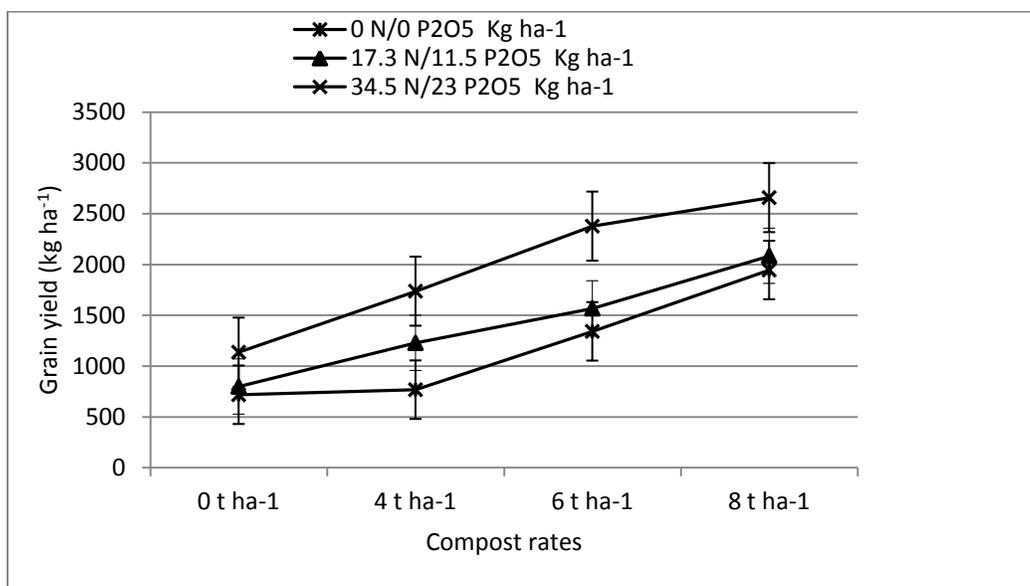


Figure 1. Current (a) and residual (b) effect of compost and inorganic fertilizers on wheat grain yield at Gumara-Maksegnit watershed

Both in the current and residual effects, straw yield responded only to the main treatment effects of compost and inorganic fertilizers, but not to the interaction effect. Averaged over all N/P fertilizer levels, straw yield increased with an increase in compost rate, with the highest significant straw yield recorded with the application of 8 t compost ha⁻¹ (Fig. 2a). With regard to response to inorganic fertilizers, both in the current and residual effects, averaged

over all compost levels straw yield was significantly higher with the application of 34.5–23 kg N–P₂O₅ ha⁻¹(Fig. 2b). Straw yield in the residual plots was generally low compared to the current application.

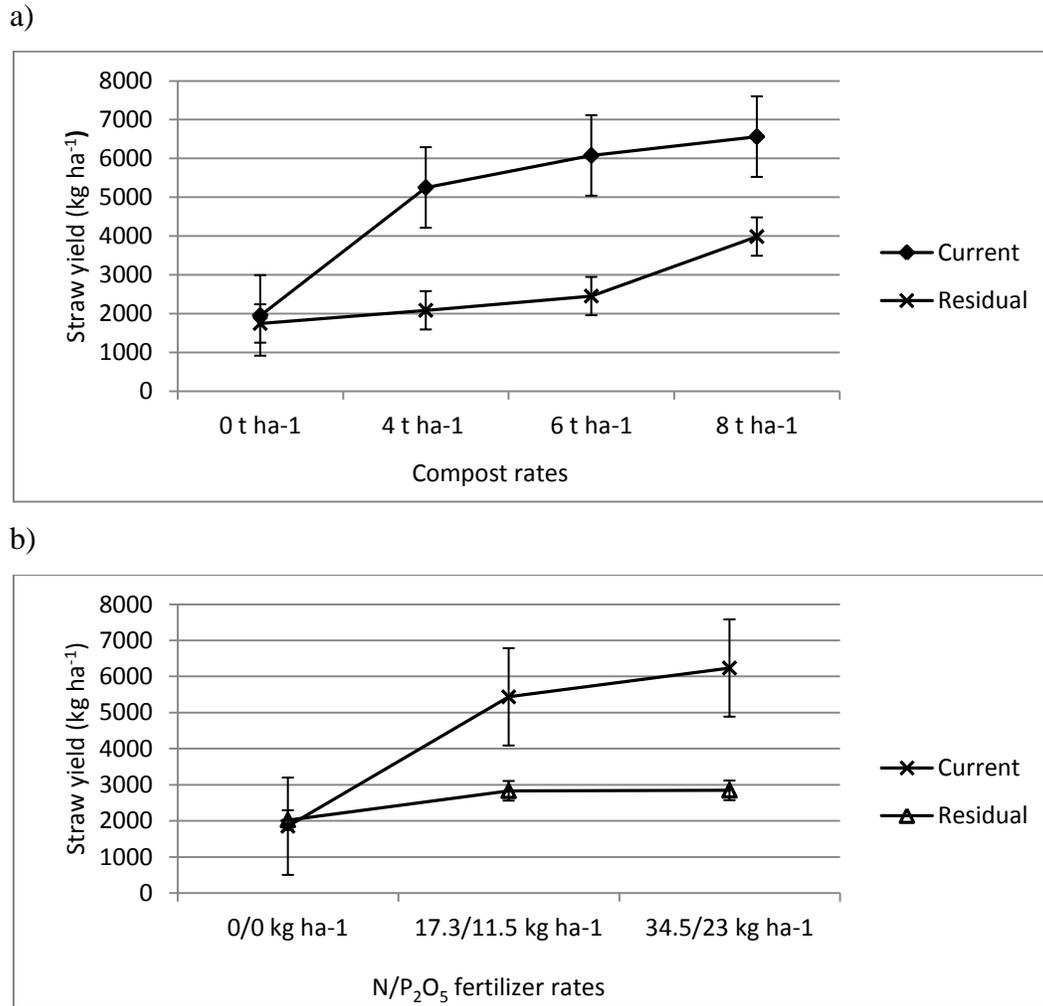


Figure 2. Current and residual effect of compost (a) and inorganic fertilizers (b) on wheat straw yield at Gumara-Maksegnit watershed

Grain protein content

Grain protein content responded to the main effects of compost and inorganic fertilizers, but not to the interaction effect (Table 2). Averaged over the levels of N–P fertilizers, grain protein content increased following the current as well as the residual increase in compost rate. Significantly higher grain protein content was recorded at 8 t compost ha⁻¹ (Fig. 3a). Averaged over the levels of compost, grain protein content was significantly higher with the application of 34.5–23 kg N–P₂O₅ ha⁻¹ (Fig. 3b).

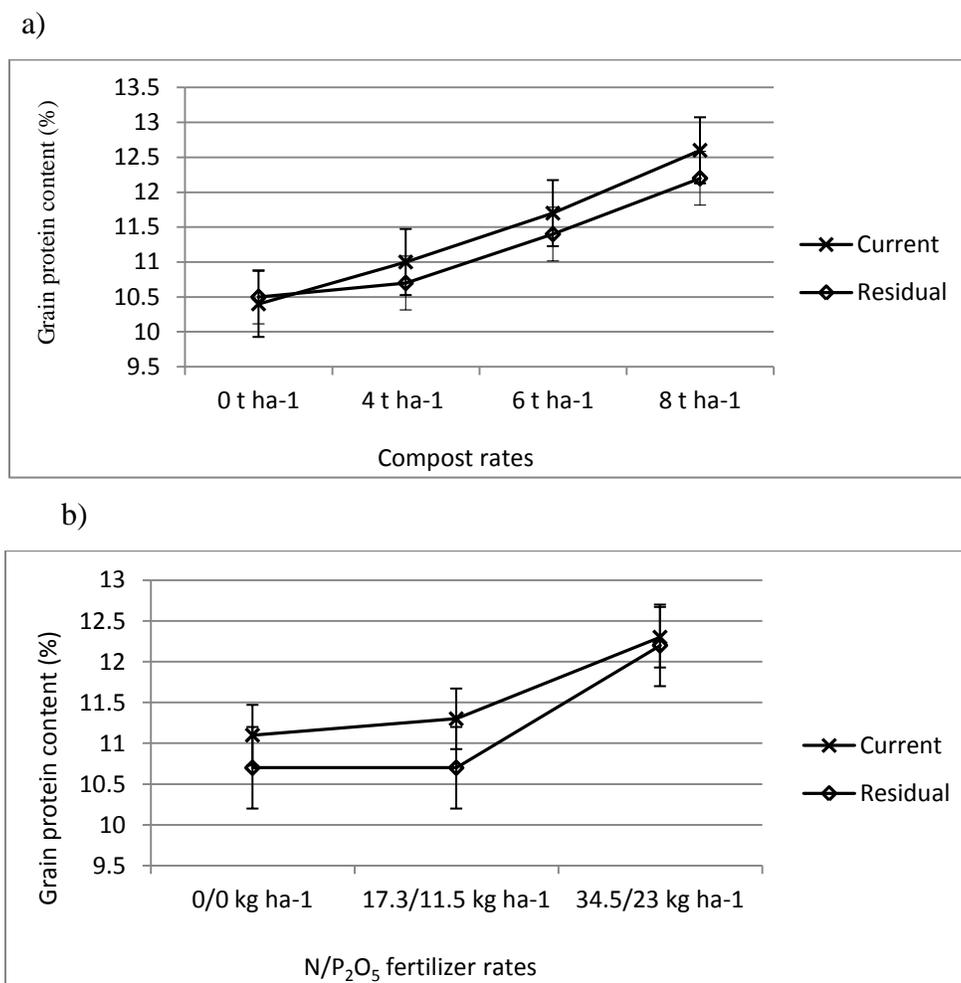


Figure 3. Current and residual effect of compost (a) and inorganic fertilizers (b) on wheat grain protein content at Gumara-Maksegnit watershed

Soil chemical properties

In both the current and residual effects, when averaged over the NP rates compost application significantly increased available P, organic matter, exchangeable Ca contents and CEC of the soil (Fig. 4). Nevertheless, compost application did not have significant effect on soil pH and on exchangeable Mg, K and Na contents. Applying 8 t compost ha⁻¹ in the current trial, and 4, 6 and 8 t compost ha⁻¹ in the residual effect trial gave significantly higher available P (Fig. 4a). Organic matter content was significantly higher for 4, 6 and 8 t compost ha⁻¹ both in the current and residual effects trials (Fig. 4b). Exchangeable Ca content was significantly higher in the current trial when applying 6 and 8 t compost ha⁻¹, and 8 t compost ha⁻¹ in the residual effects trial (Fig.

4c). CEC was significantly higher in the current trial when applying 8 t compost ha⁻¹ and 6 and 8 t compost ha⁻¹ in the residual effects trial (Fig. 4d). In the current effect trial, applying 4, 6 and 8 t compost ha⁻¹ increased available P content by 89–161 %, organic matter content by 84–108 %, exchangeable Ca content by 5–17 %, and CEC by 9–15 % over the plot with no compost. Similarly, for the same compost application rates in the residual effects trial, available P increased by 138–173 %, organic matter by 79–104 %, exchangeable Ca by 4–17 % and CEC by 11–17 %.

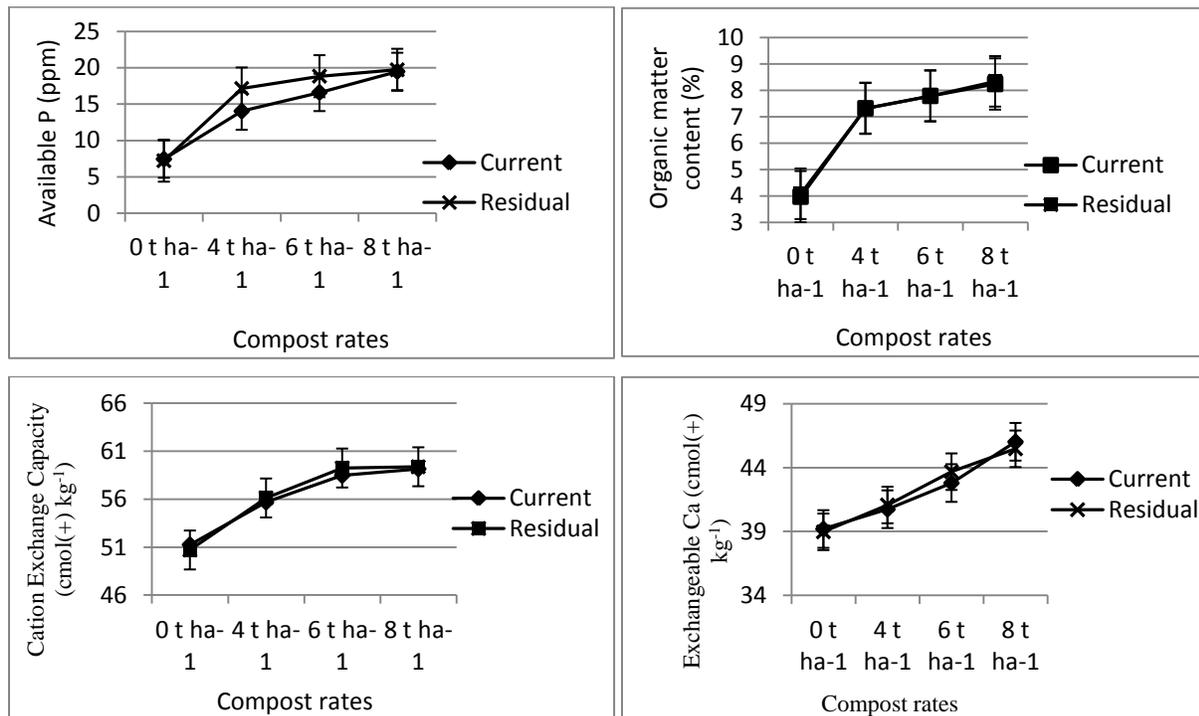


Figure 4. Current and residual effects of compost on soil available P and organic matter content, cation exchange capacity and exchangeable Ca content at Gumara-Maksegnit watershed

Economic analysis

The partial budget analysis showed that treatment combination 6 t ha⁻¹ compost and 34.5–23 kg N–P₂O₅ ha⁻¹ is economically profitable as it gives a rate of return above the 100 % acceptable rate of return.

Although the highest MRR (1,732 %) was recorded for the treatment combination 4 t ha⁻¹ compost and 17.3–11.5 kg N–P₂O₅ ha⁻¹, farmers’ overall net income could improve if an additional investment is made further to applying 6 t ha⁻¹ compost and 34.5–23 kg N–P₂O₅ ha⁻¹ with MRR of 844 % (Table 3). The calculated MRR tells that by using this combination of fertilizers, farmers can get a return of US\$8.44 for every US\$1.0 of additional investment on organic and inorganic fertilizers. The economic analysis result agrees with the agronomic result.

Table 3 Economic analysis for the use of compost and inorganic fertilizer on bread wheat in Gumara-Maksegnit watershed

Compost (t ha ⁻¹)	Inorganic fertilizer (N/P ₂ O ₅)	Grain yield (kg ha ⁻¹)	Straw yield (t ha ⁻¹)	Adjusted grain yield (kg ha ⁻¹)	Adjusted straw yield (t ha ⁻¹)	Gross field benefits (US\$ ha ⁻¹)	Total cost that vary (US\$ ha ⁻¹)	Net benefit (US\$ ha ⁻¹)	Dominance	MRR ^a
0	0–0	604	1.9	543.6	1.71	246.4	0	246.42		
0	17.3–11.5	1,233	2.1	1,109.70	1.89	501.3	37.7	463.65		576
4	0–0	1,514	2.6	1,362.60	2.34	615.6	61.04	554.59		390
0	34.5–23	1,538	2.7	1,384.20	2.43	625.4	74.75	550.69	D	
6	0–0	2,057	2.7	1,851.30	2.43	835.6	91.56	744.08		621
4	17.3–11.5	2,381	3	2,142.90	2.7	967.1	98.74	868.4		1,732
8	0–0	2,727	3.6	2,454.30	3.24	1,107.80	122.08	985.76		503
6	17.3–11.5	2,576	3.6	2,318.40	3.24	1,046.70	129.26	917.42	D	
4	34.5–23	2,587	5.3	2,328.30	4.77	1,052.70	135.79	916.95	D	
8	17.3–11.5	2,707	3.8	2,436.30	3.42	1,099.90	159.78	940.15	D	
6	34.5–23	3,752	6.1	3,376.80	5.49	1,525.30	166.31	1,359.01		844
8	34.5–23	3,279	6.6	2,951.10	5.94	1,334.20	196.83	1,137.40	D	

Discussions

Grain and straw yields

Compost application is reported to have positive effect on the physicochemical and biological properties of the soil which often leads to higher crop growth and yield (Abedi *et al.*, 2010; Hafidi *et al.*, 2012). Compost provides a steady supply of nutrients to the crop, thus improving productivity (Hafidi *et al.*, 2012). In our study, grain yield increased significantly by the

nutrients from the compost (Seran *et al.*, 2010; Suge *et al.*, 2011). Compost application, besides improving the physico-chemical properties of the soil, slowly releases nutrients and prevents nutrient losses from the inorganic fertilizers by binding to nutrients and releasing them with time (Arshad *et al.*, 2004; Abedi *et al.*, 2010). Consequently, the combined use of organic fertilizers with inorganic fertilizers improves inorganic fertilizer use efficiency and thus reduce the amount of inorganic fertilizer required (Bayu *et al.*, 2006a; Abedi *et al.*, 2010; Tilahun-Tadesse *et al.*, 2013). The increase in yield could be attributed to better root development and nutrient uptake resulting from improved soil structure due to compost effects. Also the positive effects of compost in preventing the loss of nutrients from chemical fertilizers and promoting a slow nutrient release with the passage of time could result in higher crop yields (Arshad *et al.*, 2004; Abedi *et al.* 2010). Several reseachers (Bayu *et al.*, 2006b; Abedi *et al.*, 2010; Tilahun-Tadesse *et al.*, 2013) have reported that organic inputs have improved the physical properties of the soil which would have caused increased root development and thus increased nutrient and water uptake.

Grain protein content

It is widely reported that protein content in wheat grain, which is strongly associated with bread-making quality, often improves with sufficient nutrient supply (Takahashi *et al.*, 2006; Abedi *et al.*, 2010). In this study grain protein content has significantly increased with the compost and inorganic fertilizers application. Grain protein content increased 21 and 16 % with the current and residual effects, respectively, of 8 t compost ha⁻¹. Similarly, grain protein content increased 11 and 14 % with the current and residual effects, respectively, of 34.5–23 kg N–P₂O₅ ha⁻¹. Similar

to these results, Abedi *et al.*, (2010) reported increase in wheat grain protein content in response to applying 6 t compost ha⁻¹. Hossain *et al.*, (2012) also reported a significantly higher grain protein (10.08 %) in maize from applying 22.5 t compost ha⁻¹ and N–P–K (30–15–20 kg ha⁻¹), respectively as compared to the protein content in the control (4.85 %). The increase in grain protein content with compost and inorganic fertilizer application could be ascribed to more nutrient availability and increased nutrient uptake as a result of improved soil structure (Abedi *et al.*, 2010). In countries where cereal grains are the major source of protein for human

consumption, increase in grain protein content by improving soil fertility could be taken as a least-cost approach to improve human nutrition.

Soil chemical properties

Compost addition to soil has long been considered important in maintaining the quality of the soil, basically in terms of improving its physical, chemical and biological properties (Sarwar *et al.*, 2008; Hepperly *et al.*, 2009; Hafidi *et al.*, 2012). In our study, the current and residual effects of compost have improved many soil chemical properties. Soil organic matter (SOM), regarded as a key factor in determining soil fertility and productivity, and increased 108 % in the current and 104 % in the residual effect, respectively, of 8 t compost ha⁻¹. Several research reports have shown improvement in the SOM content with organic fertilizer application. In a rice–wheat rotation Sarwar *et al.*, (2008) reported a rise in SOM content from 0.56 to 0.98 % after rice and from 0.67 to 1.30 % after wheat with the application of 24 t compost ha⁻¹ with a recommended fertilizer rate (100–70–70 kg ha⁻¹ N–P–K). Reeve *et al.* (2012) reported a 1.6-fold higher total organic C (1.43 vs. 0.89 %, $p < 0.002$), in a soil that was amended with compost 16 years before, compared to a soil that was not amended. Increase in SOM as a result of compost application has great implication in terms of improving soil productivity as SOM is the ultimate source of nutrients and microbial activity in the soil. SOM also has a major role in improving soil structure, water holding capacity, infiltration rate, aeration and porosity of the soil as well as reducing environmental pollution due to the carbon sequestration effect (Sarwar *et al.*, 2008).

Compost contains macro and micro nutrients (Eyheraguibel *et al.*, 2008; Hafidi *et al.*, 2012). Several studies (Abedi *et al.*, 2010; Hafidi *et al.*, 2012) have shown that humic substances in compost enhance the availability of macro and micro nutrients (N, P, K, Mg, and Ca). In our study, available soil P increased 162 % in the current trial and 173 % in the residual effect trial, respectively, due to the application of 8 t compost ha⁻¹. Similar results were reported by Sarwar *et al.* (2008) who reported an increase in available P from 5.72 mg kg⁻¹ in the control to 27.55 mg kg⁻¹ with the application of 24 t compost ha⁻¹ and 100–70–70 kg N–P–K ha⁻¹. The increase in available P could be, according to Singh *et al.* (2008), due to the addition of P through compost in excess of removal by the crop. It could also be due to the fact that organic manures, on decomposition, solubilize insoluble organic P fractions through release of various

organic acids, thus resulting in a significant improvement in soil available P content (Sharma *et al.*, 2013). In this study, exchangeable Ca content increased 16.7 % in the current trial and 17.4 % in the residual effect trial, respectively, due to the application of 8 t compost ha⁻¹. In agreement to this result, Hafidi *et al.*, (2012) reported an increase in Ca content from 1,399.7 to 2,109.9 mg kg⁻¹ with the application of 28 t compost ha⁻¹. They also reported an increase in the levels of saturation of other alkaline elements (K, Na) with the application of 28 and 42 t compost ha⁻¹, effect that was not observed in this study. According to Sarwar *et al.* (2008) the increase in Ca and Mg with compost application could be due to the reaction of organic acids with CaCO₃ and Mg salts. The increase could also be from the addition of Ca from the compost itself as it has high content of Ca (Table 1). Cation exchange capacity is a key soil chemical property characterizing the adsorption capacity of a soil. Increase in the soil CEC implies that the soil will be able to retain nutrients in the soil–plant system in larger quantities and for longer time. Hence the crop will utilize nutrients more effectively, while reducing nutrient loss by leaching. In this study, CEC of the soil increased 15.4 % in the current trial and 17.1 % in the residual effect trial, respectively, due to the application of 8 t compost ha⁻¹. In line with this result, Ouedraogo *et al.*, (2001) reported a significant increase in CEC with the application of 10 t ha⁻¹ compost in Burkina Faso. Hafidi *et al.*, (2012) have shown an increase in CEC from 35.6 meq/100 g in the control plot to 46.8 meq/100 g, 46.9 meq/100 g and 47.2 meq/100 g by applying 14, 28 and 42 t compost ha⁻¹, respectively. The increase in CEC with compost application could be attributed to an increase in soil organic matter content (Ouedraogo *et al.*, 2001). The observed increase in the nutrient contents of the soil in the residual plots in this study could be due to the fact that nutrients contained in compost are stored for longer time in the soil and are released more slowly, thereby ensuring a long residual effect (Sharma and Mittra, 1991) and to solubilisation of nutrients from soil minerals due to the effect of compost's organic acids (Sharma *et al.*, 2013).

Economic analysis

Financial profitability is the ultimate measure to recommend a technology. Any technology that is agronomically feasible and is beneficial for soil improvement would not be attractive to farmers unless it is financially profitable. In the current study, by applying 6 t compost ha⁻¹ with 34.5–23 kg N–P₂O₅ ha⁻¹ farmers in the watershed will be able to gain US\$8.44 for each US\$1.0 investment, which implies a very high increase in farmers' income with a simple improvement in

soil fertility management. This financial benefit is in addition to the benefit in terms of soil improvement which we could not quantify in terms of monetary value.

Conclusions

Using compost for soil quality and productivity improvement has been receiving much attention by the government of Ethiopia. In this study, it was found that the combined use of compost and inorganic fertilizers improve the overall soil fertility and wheat productivity. Generally, soil quality and productivity may be more sustainable with the integrated application of compost and inorganic fertilizers than with the use of inorganic fertilizers alone. From the results of the current experiment, it could be concluded that combined applications of 6 t compost ha⁻¹ with 34.5–23 kg N–P₂O₅ ha⁻¹ resulted in the improvement of most soil physicochemical properties and yield and grain quality of wheat over 2 years. This implies that by combining compost with inorganic fertilizers farmers would be able to reduce the inorganic fertilizer requirement by 50 %. With these rates of compost and inorganic fertilizer application in the previous year farmers could get a yield benefit as much as 271 % without any compost and inorganic fertilizer application in the current year. The combined use of compost and inorganic fertilizers, therefore, is a viable technology to combat soil degradation and to increase productivity.

However, despite the short term benefits recorded in this study, the viability of using compost in crop production will depend on the willingness and interest of farmers in producing compost. Extensive demonstration and training is required to show farmers the agronomic importance and economic value of compost application on improving the productivity of their soils.

References

- Abedi, T., Alemzadeh, A. and Kazemeini S. A. 2010. Effect of organic and inorganic fertilizers on grain yield and protein banding pattern of wheat. *Aust J Crop Sci* 4:384–389
- Arshad M, Khalid A, Mahmood MH, Zahir ZA (2004) Potential of nitrogen and L-tryptophan enriched compost for improving growth and yield of hybrid maize. *Pak J Agric Sci* 41:16–24
- Ayuk, E. T. 2001. Social, economic and policy dimensions of soil organic matter management in Sub-Saharan Africa: challenges and opportunities. *Nutr Cycl Agroecosyst* 61:183–195
- Bationo, A., Lompo, F. and Koala S. 1998. Research on nutrient flows and balances in West Africa: state-of-the-art. *Agric Ecosyst Environ* 71:19–35
- Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. and Kimetu J. 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agric Syst* 94:13–25
- Bayu, W., Rethman, N.F.G., Hammes, P. S. and Alemu G. 2006a Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. *J Plant Nutr* 29:391–407
- Bayu, W., Rethman, N.F.G., Hammes, P. S. and Alemu G. 2006b. Application of farmyard manure improved the chemical and physical properties of the soil in a semi-arid area in Ethiopia. *Biol Agric Hortic* 24:293–300
- CIMMYT (International Maize and Wheat Improvement Centre). 1988. From agronomic data to farmer recommendation: an economics training manual completely revised edition. CIMMYT, Mexico
- Eyheraguibel, B., Silvestre, J. and Morard P. 2008. Effects of humic substances derived from organic waste enhancement on the growth and mineral nutrition of maize. *Bioresour Technol* 99:4206–4212
- Hafidi, M., Amir, S., Meddich, A., Jouraiphy, A., Winterton, P., El Gharous, M. and Duponnois R. 2012. Impact of applying composted biosolids on wheat growth and yield parameters on a calcimagnesian soil in a semi-arid region. *Afr J Biotechnol* 11:9805–9815
- Hepperly, P., Lotter, D., Ulsh, C.Z., Seidel, R. and Reider C. 2009. Compost, manure and synthetic fertilizer influences crop yields, soil properties, nitrate leaching and crop nutrient content. *Compost Sci Util* 17:117–126

- Hossain, N., Kibria, M. G. and Osman K. T. 2012. Mineral nutrition and quality of maize (*Zea Mays L.*) as affected by household waste compost, poultry manure and inorganic fertilizers IOSR. *J Pharm Biol Sci* 3:44–52
- Jackson M. L. 1958. Soil chemical analysis. Prentice Hall of India, New Delhi
- Lakew Desta, Menale Kassie, Benin, S. and Pender J. 2000. Land degradation and strategies for sustainable development in the Ethiopian highlands: Amhara Region. Socio-economics and policy research working paper 32. ILRI (International Livestock Research Institute), Nairobi, Kenya. p 122
- Nahar, K., Haider, J. and Karim A.J.M.S. 1995. Residual effect of organic manures and influence of nitrogen fertilizer on soil properties and performance of wheat. *Ann Bangl Agric* 5:73–78
- NMSA (National Meteorological Service Agency). 2009. Climate and agro-climate resource of Ethiopia. National Meteorological Service Agency, Bahir Dar
- Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *USDA Circular No 939*:1–19
- Ouedraogo, E., Mando, A. and Zombre N.P. 2001. Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agric Ecosys Environ* 84:259–266
- Page, A.L., Miller, R.H. and Keeney D.R. 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties, 2nd edn. Soil Science Society of America, Madison
- Reeve, J. R., Endelman, J. B., Miller, B. E. and Hole D. J. 2012. Residual effects of compost on soil quality and dryland wheat yield sixteen years after compost application. *Soil Sci Soc Amer J* 76 (1):278–285
- Sahilemedin Sertsu and Taye Bekele. 2000. Procedure for soil and plant analysis. National Soil Research Center, Ethiopian Agricultural Research Organization, Addis Abeba
- Sanchez, A. P. and Leakey R.R.B. 1997. Land use transformation in Africa: three determinants for balancing food security with natural resource utilization. *Europ J Agron* 7:5–23
- Sanchez, A. P., Shepherd, K.D., Soule, M. J., Buresh, R. J. and Izac A.M.N. 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh RJ, Sanchez AP, Calhoun F (eds) *Replenishing soil fertility in Africa*. SSSA Special publication No. 51, Madison, pp 1–46

- Sarwar, G., Hussain, N., Schmeisky, H. and Muhammad S. 2007. Use of compost an environment friendly technology for enhancing rice-wheat production in Pakistan. *Pak J Bot* 39:1553–1558
- Sarwar, G., Schmeisky, H., Hussain, N., Muhammad, S., Ibrahim, M. and Safdar E. 2008. Improvement of soil physical and chemical improvement with compost application in rice-wheat cropping system. *Pak J Bot* 40:275–282
- Seran, T. H., Srikrishnah, S. and Ahamed M.M.Z. 2010. Effect of different levels of inorganic fertilizers and compost as basal application on the growth and yield of onion (*Allium cepa* L.). *J Agric Sci* 5:64–70
- Sharma, A. R. and Mittra B. N. 1991. Effect of different rates of application of organic and nitrogen fertilizers in a ricebased cropping system. *J Agric Sci* 117:313–318
- Sharma, G. D., Thakur, R., Som, R., Kauraw, D. L. and Kulhare P. S. 2013. Impact of integrated nutrient management on yield, nutrient uptake, protein content of wheat (*Triticum astivum*) and soil fertility in Typic Haplustert. *Bioscan* 8:1159–1160
- Singh, F., Kumar, R. and Pal S. 2008. Integrated nutrient management in rice-wheat cropping system for sustainable productivity. *J Indian Soc Soil Sci* 56:205–208
- Solomon, D., Fritzsche, F., Tekalign, M., Lehmann, J. and Zech W. 2002. Soil organic matter composition in the Subhumid Ethiopian highlands as influenced by deforestation and agricultural management. *Soil Sci Soc Am J* 66:68–82
- Stoorvogel, J. J., Smaling, E. M. A. and Janssen B. H. 1993. Calculating soil nutrient balances in Africa at different scales: i Supranational scale. *Fertil Res* 35:227–235
- Suge, J.K., Omunyin, M. E. and Omami E. N. 2011. Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (*Solanum Melongena* L). *Arch Appl Sci Res* 3(6):470–479
- Takahashi, S., Anwar, M. R. and de Vera S. G. 2006. Effects of compost and nitrogen fertilizer on wheat nitrogen use in Japanese soils. *Agron J* 99:1151–1157
- Tilahun A. 2003.1 0 0 1 137.66 212.21 Tm2.06 170.78 Tm[Oppogtu(nit)23(ien)-278(a)4(nd)2179(c)4(ua)4(lt

Tilahun Tadesse F, Nigussie Dechassa R, Wondimu B, Setegn G. 2013 Effect of farmyard manure and inorganic fertilizers on the growth, yield and moisture stress tolerance of rain-fed lowland rice. *Am J Res Com* 1:275–301

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin J. L. 1993. *Soil fertility and fertilizers*, 5th edn. Macmillan Publishing Company, USA

Voortman, R. L., Sonneveld, B. G. and Keyzer M. A. 2000. *African land ecology: Opportunities and constraints for agricultural development*. Center for international development working paper 37. Cambridge, Mass, USA