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ORIGINAL ARTICLE

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

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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 (0–0, 17.3–5, 34.5–10 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 108 and 104 %; available P 162 and 173 %; exchangeable Ca 16.7 and 17.4 %; and *CEC* 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 · Vertisol

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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, defined as "a net decrease in available nutrients and organic matter in the soil" (Voortman et al. 2000). Continuous and intensive cropping without any effort to restore soil fertility has depleted the nutrient base of most soils (Bationo et al. 1998). Increasing population pressure on agricultural land has resulted in higher nutrient outflows thus creating a vicious circle of food insecurity and poverty (Sanchez et al. 1997). The need to tackle soil fertility depletion is thus a fundamental biophysical constraint to ensure food security in Africa (Sanchez and Leakey 1997).

It is well recognized that soil organic matter plays a major role in soil fertility by affecting physical and chemical properties, and also controling 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 has 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 120°23′53″ to 120°30′49″ latitude and 370°33′39″ to 370°37′14″ longitude and an altitude of 1,953 m above sea level. The soil at the experimental site is classified as Vertisol. The long term average annual rainfall is ≈1,052 mm. The mean minimum and maximum temperatures of the area are 13.3 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

Table 1 Chemical properties of the compost used in the field experiments

Chemical properties	Values
pH	6.46
Available P (mg kg^{-1})	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

water), 3.96 % organic matter, 0.19 % total N, 6.4 mg kg^{-1} 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^{-1} Na, and cation exchange capacity (*CEC*) of 58.40 $cmol^{(+)}$ kg^{-1}.

Experimental design and procedures

The study was conducted in 2011 and 2012. In 2012, two sets of trials were conducted: one is the repetition of the 2011 experiment on a new experimental plot and the second is a residual effect study conducted on the experimental plots of 2011. 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 inorganic fertilizer combinations, 0–0, 17.3–5, 34.5–10 kg N–P ha^{-1}. The fertilizer combinations are 0, 25, and 50 % of the recommended 69 kg N ha^{-1} and 20 kg P ha^{-1} fertilizer rates, respectively. The experimental design was a randomized complete block with three replications. A compost prepared through heap method out of 40 % cactus and crop residue, 10 % vegetable and fruit peels (avocado, mango and vegetable skins), 20 % animal manure, 10 % ash, 5 % soil, and 15 % cattle urine was applied on dry weight basis, spread evenly, and incorporated into the top 10 cm soil layer 2 weeks before planting. The chemical properties of the compost used for the study are presented in Table 1. The application of 4, 6 and 8 t compost ha^{-1} implies addition of 0.19, 0.29, and 0.38 kg available P ha^{-1}; 40, 60, and 80 kg exchangeable Ca ha^{-1}; 7, 10.5, and 14 kg exchangeable Mg ha^{-1}; 1.9, 2.8, and 3.7 kg exchangeable K ha^{-1}; and 0.8, 1.1, and 1.5 kg exchangeable Na ha^{-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 and var. Tay were planted in 2011 and 2012, respectively, in rows at the seed rate of 125 kg ha^{-1}. Planting was made on broad bed and furrows to facilitate water drainage. Gross and net plot sizes were 6 m × 6 m and 5 m × 5 m, respectively. Weeds were removed manually as needed. No insecticide or fungicide was applied as there was no serious incidence of insect pests or diseases.

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).

In the current effect, the highest significant grain yield was obtained applying 6 t compost ha^{-1} with 34.5–10 kg N–P ha^{-1} followed by applying 8 t compost ha^{-1} with 34.5–10 kg N–P 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 34.5–10 kg N–P ha^{-1} applied in the preceding season (Fig. 1).

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 34.5–10 kg N–P ha^{-1} (Fig. 2b). Straw yield in the residual plots was generally low compared to the current application.

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 34.5–10 kg N–P ha^{-1} (Fig. 3b).

Soil chemical properties

In both the current and residual effects, when averaged over the N–P 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

Table 2 Analysis of variance for the effect of compost and inorganic fertilizers on grain yield, straw yield and grain protein content (GPC) of bread wheat, in the Gumara-Maksegnit watershed

Source of variation	df	Current			Residual		
		Grain yield	Straw yield	GPC	Grain yield	Straw yield	GPC
Compost (C)	3	1,276,765.05**	4,760,653.44**	8.92**	1,201,952.6**	2,503,855.4**	8.3**
Inorganic fertilizer (F)	2	3,872,445.98**	7,201,779.07**	6.04**	3,084,720.2**	5,391,588.4**	7.6**
C × F	6	2,434,768.83**	1,181,063.74 ns	0.63 ns	67,796.1**	1,097,806.4.74 ns	0.63 ns
Error	24	42,637.71	980,580.57	0.42	42,131.7	334,585.1	0.48

** and ns denote significant difference at $P \leq 0.01$ and non-significant difference, respectively

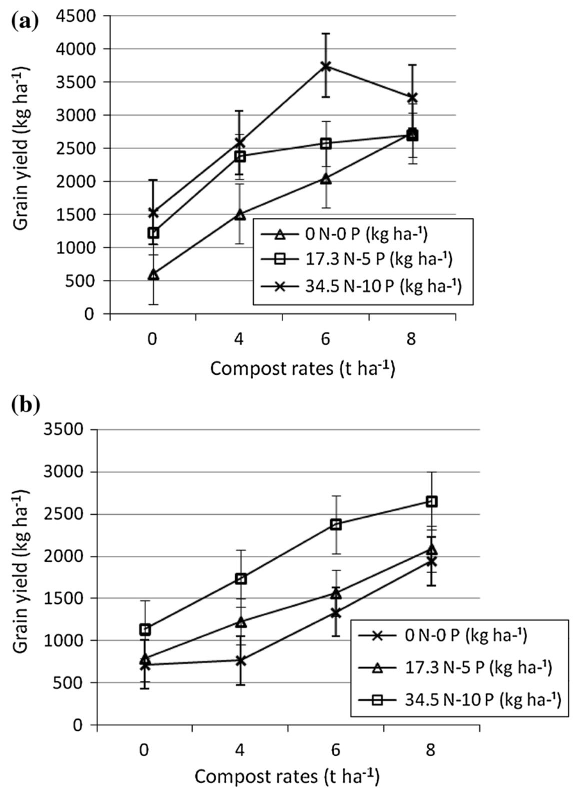

Fig. 1 Current (**a**) and residual (**b**) effects of compost and inorganic fertilizers on mean wheat grain yield, at the Gumara-Maksegnit watershed. *Vertical bars* represent ± SE

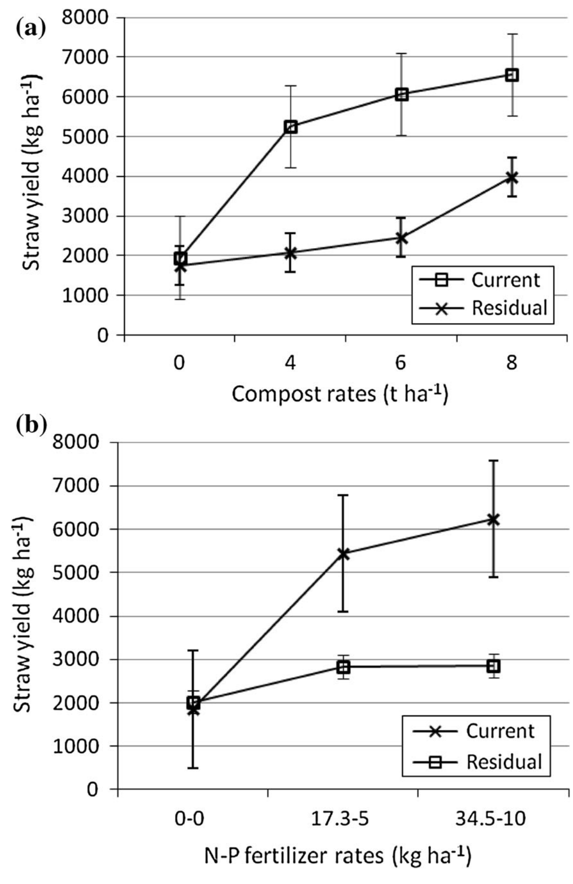

Fig. 2 Current and residual effects of compost (**a**) and inorganic fertilizers (**b**) on mean wheat straw yield at the Gumara-Maksegnit watershed. *Vertical bars* represent ± SE

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

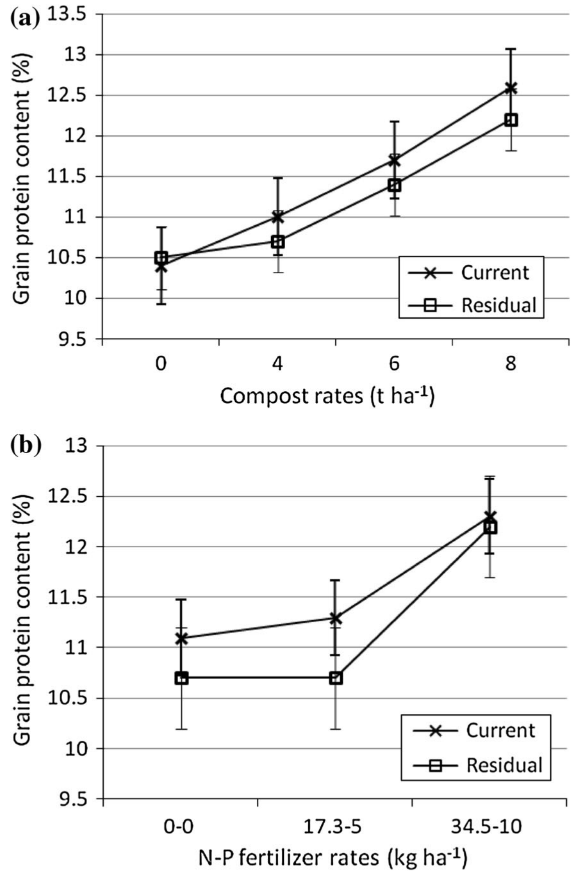

Fig. 3 Current and residual effects of compost (**a**) and inorganic fertilizers (**b**) on mean wheat grain protein content at the Gumara-Maksegnit watershed. *Vertical bars* represent ± SE

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 %.

Economic analysis

The partial budget analysis showed that treatment combination 6 t ha^{-1} compost and 34.5–10 kg N–P 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 17.3–5 kg N–P ha^{-1}, farmers' overall net income could improve if an additional investment is made further to applying 6 t ha^{-1} compost and 34.5–10 kg N–P 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.

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 application of compost together with inorganic fertilizers. Applying 6 t compost ha^{-1} with 34.5–10 kg N–P ha^{-1} gave a yield increase of 521 % over the control, and the application of 8 t compost ha^{-1} with 34.5–10 kg N–P ha^{-1} gave a yield increase of 442 %. The residual effect from 1 year application of compost and inorganic fertilizers also gave yield benefits ranging from 7 to 271 %. This indicates that farmers who cannot afford to apply compost every year could improve productivity by as much as 271 % by applying compost every other year. These results are in agreement with other reports on rice (Sarwar et al. 2007), wheat (Sarwar et al. 2007; Abedi et al. 2010) and sorghum (Ouedraogo et al. 2001). Nahar et al. (1995) reported 97 % yield increase in wheat from residual effects of compost.

Wheat straw yield increased by 169–236 % when the compost was applied and by 19–128 % in the following season, due to the residual effects of compost. Straw yield also increased 193–237 % in the current and 40 % in the residual season, respectively, as a response to inorganic fertilizer application. Similar results, where significant increase in rice and wheat straw due to the combined application of 12 and 24 t compost ha^{-1}, respectively, and N, P, K fertilizers were reported by Sarwar et al. (2007). Wheat straw is an important dry season livestock feed in the watershed. Thus, the observed increase in straw yield

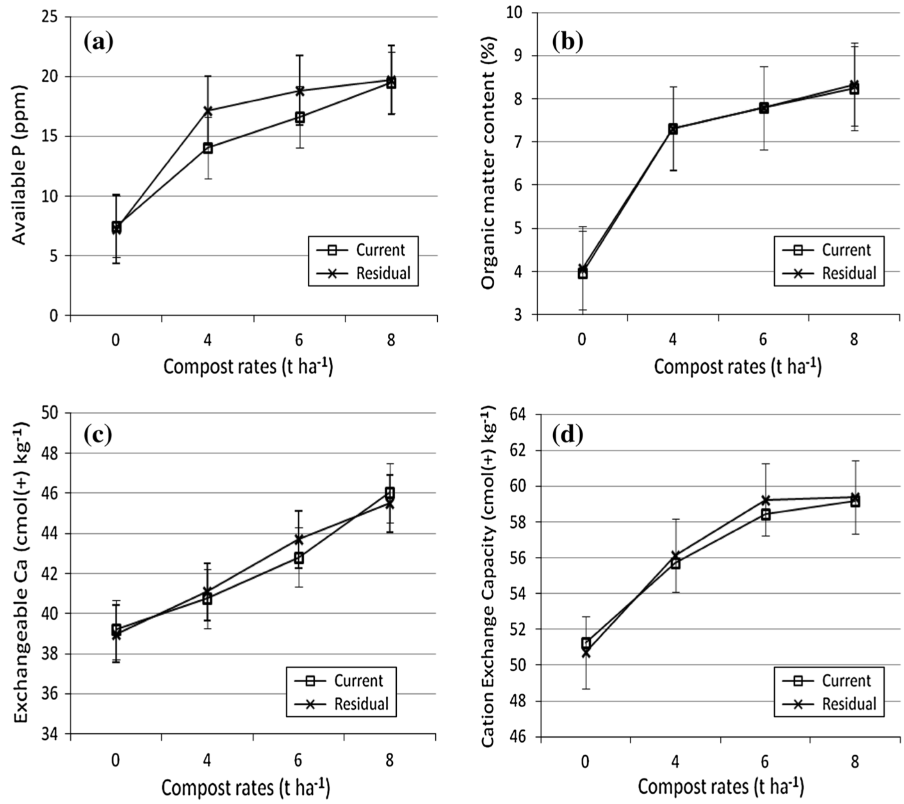

Fig. 4 Current and residual effects of compost on mean soil available P (**a**), organic matter content (**b**), and exchangeable Ca (**c**) content and CEC (**d**) at Gumara-Maksegnit watershed. *Vertical bars* represent ± SE

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

Compost (t ha^{-1})	N–P fertilizer (kg ha^{-1})	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	0.00	246.42		
0	17.3–5	1,233	2.1	1,109.7	1.89	501.3	37.70	463.65		576
4	0–0	1,514	2.6	1,362.6	2.34	615.6	61.04	554.59		390
0	34.5–10	1,538	2.7	1,384.2	2.43	625.4	74.75	550.69	D	
6	0–0	2,057	2.7	1,851.3	2.43	835.6	91.56	744.08		621
4	17.3–5	2,381	3	2,142.9	2.7	967.1	98.74	868.40		1,732
8	0–0	2,727	3.6	2,454.3	3.24	1,107.8	122.08	985.76		503
6	17.3–5	2,576	3.6	2,318.4	3.24	1,046.7	129.26	917.42	D	
4	34.5–10	2,587	5.3	2,328.3	4.77	1,052.7	135.79	916.95	D	
8	17.3–5	2,707	3.8	2,436.3	3.42	1,099.9	159.78	940.15	D	
6	34.5–10	3,752	6.1	3,376.8	5.49	1,525.3	166.31	1,359.01		844
8	34.5–10	3,279	6.6	2,951.1	5.94	1,334.2	196.83	1,137.40	D	

[a] Marginal rate of return

has implication on livestock feed availability and livestock productivity by ensuring a higher supply of feed. The extra straw achieved as a result of compost application could also be used either for soil application to maintain the organic matter content or could be sold to generate income.

Increase in grain and straw yields from the combined application of compost and inorganic fertilizers could be attributed to better crop growth, due to the readily available nutrients from the inorganic fertilizer sources and the improved nutrient availability and controlled release of 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 lose 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 34.5–10 kg N–P 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, 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 $CaCO_3$ 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 34.5–10 kg N–P 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 34.5–10 kg N–P ha^{-1} resulted in 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.

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