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Evaluation of Crop Residue Retention, Compost and Inorganic Fertilizer Application on Barley Productivity and Soil Chemical Properties in the Central Ethiopian Highlands

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Abstract

Soil fertility depletion is a serious problem in the highlands of Ethiopia. A field experiment was conducted for two consecutive cropping seasons (2009-2010) on farmers' fields in Degem Wereda, North Shewa, Oromiya Regional State. The objective of this study was to evaluate the effects of crop residue, compost, inorganic fertilizer and cropping system as a component of an integrated soil fertility and plant nutrient management system on barley productivity and soil chemical properties. The treatments included eight selected combinations of organic and inorganic nutrient sources, including retention of crop residues. The design was randomized complete block with three replications. Results showed that barley yield and some yield components significantly responded to the application of different soil fertility management practices. The highest barley grain yield (2575 kg/ha) and total biomass (5185 kg/ha) were obtained from the applications of the recommended nitrogen and phosphorus (NP) fertilizer followed by 2353 and 5148 kg/ha for grain yield and total biomass, respectively, due to the applications of half doses of the recommended NP fertilizer and 3 t/ha EM-compost. The grain yield of barley consistently increased as the total biomass increased. Although the highest yields were achieved from the application of the recommended NP fertilizer rate, the other integrated soil fertility management treatments also resulted in significant yield advantages compared to the control. Yields from the applications of three treatments 1/ half the recommended rate of NP fertilizer and 3 t/ha conventional compost; 2/ retention of 30% of crop residue plus half the recommended rate of NP fertilizer and faba bean mixed intercropping; and 3/ half doses of NP fertilizer plus 3 t/ha EM-compost were almost identical. Barley grain yield showed significantly positive correlations with the total biomass (r = 0.94), spike length (r = 0.43) and number of productive tillers (r = 0.42), respectively. Partitioning of treatments into single degrees of freedom orthogonal contrasts revealed that barley grain yield, total biomass, spike length and productive tillers significantly differed due to the different soil fertility management treatments. From the results of this study, it can be concluded that application of half the recommended rate of NP fertilizer with 50% of the recommended dose of compost (3 t/ha) can be an alternative best integrated soil fertility management measure instead of only inorganic fertilizers for sustainability. The results of this experiment can be reproducible in other similar agro-ecologies and farming systems of the country.

Key words: Barley productivity, chemical soil properties, compost, crop residue, inorganic fertilizer, sustainability

Introduction

Soil fertility depletion and widespread soil degradation are the major biophysical root causes of declining per-capita food production and natural resource conservation in sub-Saharan Africa (Sanchez *et al*., 1997; Farouque and Tekeya, 2008). In Ethiopia, century-long, low-input agricultural production systems and poor agronomic management practices, limited awareness of communities and absence of proper land-use policies have aggravated soil fertility degradation. This has also prompted the expansion of farming to marginal, non-cultivable lands, including steep landscapes and rangelands. An agricultural system involving a combination of sustainable production practices has the following major attributes: it conserves resources; is environmentally non-degrading, technically appropriate, and economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses less external inputs and employs locally available natural resources more efficiently (Lee, 2005).

Conservation agriculture conserves and enhances soil organic matter. This makes it possible for fields to act as sinks for carbon dioxide, increases soil's water retention capacity and reduces soil erosion. Since the practice of conservation agriculture is less developed than traditional agriculture practice and because no research had been attempted to evaluate its application to the Ethiopian setting, Sasakawa Global (SG-2000) initiated a conservation agriculture project in 1998 to demonstrate its merits in selected maize-growing areas of the country. The results of observations in the demonstration plots revealed increased crop yields and higher incomes from the conservation agriculture plot compared to the conventional one (SG-2000, 2007). During the same period, conservation tillage and compost was included as part of agricultural extension packages to reverse extensive land degradation in Ethiopia. This implies that these two organic farming techniques can create a win-win situation, where farmers are able to reduce production costs, provide environmental benefits and increase their yields. In spite of such encouraging results, adoption of conservation agriculture is very limited or nonexistent even in areas that received significant extension outreach and experimental demonstrations. The major reasons are the need for non-selective pre-planting herbicides for weed control; lack of appropriate minimum tillage implements to facilitate seed-soil contact; and free-range grazing of animals following crop harvest that impinges upon conservation agriculture practices. Furthermore, the transition from conventional agriculture and environmental management practices to non-conventional ones represents one of the great challenges in terms of changing farmer habits and mindsets.

In Ethiopia, organic amendments such as animal dung and crop residues are largely used for competing uses, especially as household energy sources, instead of being recycled to maintain soil fertility. Bojo and Cassels (1995) reported that the use of dung cake accounts for about 50% of the total fuel supply of households especially in the highland cereal zones of the North and central Ethiopian highlands. This practice deprives the soils of important sources of organic matter and nutrients. Zenebe Gebreegziabher (2007) reported that the use of dung as fuel instead of fertilizer is estimated to reduce Ethiopia's agricultural GDP by 7%—the lack of alternative fuel sources is a significant constraint.

There are few studies that have assessed the role of crop residue management on soil properties, crop growth and yield under field conditions in Ethiopia. Asefa Taa *et al*. (2004) reported that stubble burning tended to increase wheat grain yields and decrease the severity of the grass weed *Bromus pectinatus* infestation compared to partial removal and complete retention of stubble. In contrast, Bationo *et al*. (1993) found that the use of mineral fertilizers without recycling of organic materials resulted in higher yields, but this increase was not sustainable without inclusion of soil amendments. In Ethiopia, alternative uses of crop residues as feed, roof thatching, fencing and other purposes are major constraints, in addition to low biomass productivity of crops in the area, which contribute to continuous nutrient depletion. In addition, there is a dearth of research on the use of crop residues for soil fertility management. Therefore, the objective of this study was to evaluate the effects of crop residue, compost, inorganic fertilizers management and cropping system as a component of an integrated soil fertility and plant nutrient management system on productivity of barley and soil chemical properties in the central highlands of Ethiopia.

Materials and Methods

Study area

The trial was conducted for two consecutive cropping seasons (2009-2010) on Nitisols of Degem Woreda of North Shewa, Oromia Regional State, in the Central Highlands of Ethiopia. Three sites, namely Elamoferso, Anno-Kere and Gende-Sheno with the respective altitude of 3102, 3096 and 3101 m, were selected on three farmers' fields. The rainfall is bimodal, with the long-term average annual rainfall of about 1150 mm occurring between June to September and the short rainy season running from January to April. The average maximum and minimum air temperatures of Degem Woreda are 22.09 and 10.24°C. The soil type of the experimental fields is reddish-brown (Nitisols), which is plowed using a traditional ox-drawn implement (*Maresha*). The map of the Woreda in which the experimental sites were located has been presented in Figure 1.

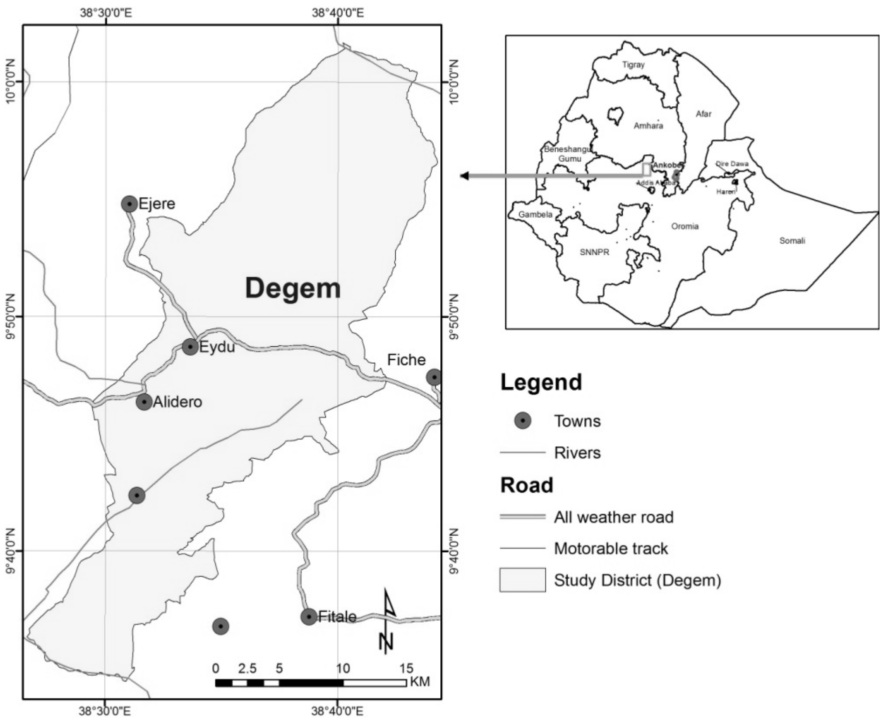

Figure 1. Map of the Woreda where the experimental sites were located

Treatments, design and data collection

The treatments were recommended nitrogen and phosphorus (NP) fertilizers either alone or in combination with compost or mixed cropping of barley with faba bean or vetch. The experiment included the following eight treatments:

1. Control – with no input and crop residue;
2. 50% barley straw as crop residue plus 50% recommended NP fertilizer;
3. Organic source - 100% recommended compost (6 t/ha);
4. 50% conventional compost (3 t/ha) plus 50% recommended NP fertilizer;
5. 30% barley straw as crop residue plus 50% recommended NP fertilizer and mixed cropping of faba bean with barley with faba bean barley seed rate proportion of 37.5%:100%;
6. 50% barley straw as crop residue plus 50% recommended NP fertilizer and under-sowing of vetch at seed rate of 20 kg/ha;
7. 50% compost treated with effective microorganisms (EM-compost) at 3t/ha and 50% recommended NP fertilizer; and
8. 100% recommended NP fertilizer (41 kg N and 20 kg P/ha).

The conventional and EM added composts were prepared separately in pits having a volume of 4 m^3 each using a mixture of plant materials and animal manure; its measurement is on a dry-weight basis. The conventional compost took three to four months, and the EM-compost one to two months. In order to prepare the EM-compost, 2 liters of EM solution plus 4 liters of molasses were mixed in 194 liters of water and incubated for one week, which is enough to spray and prepare 4 m^3 of EM-compost. Samples collected from well-decomposed compost were analyzed for N (1.1%), P (0.32%), K (1.06%), Ca (2.03%) and Mg (0.79%) using the same analytical procedures used for soil samples. Normally, the frequency of tillage for barley production in the highlands of Ethiopia is 3-4 times before planting and the last pass for seed covering during planting. In contrast, in this trial the first tillage was carried out during the application of the well-decomposed compost before planting to thoroughly mix the compost with the upper 15-20 cm of soil depth using an ox-drawn local plow. This process was supposed to facilitate nutrient release for the crop after germination. The second pass was undertaken to cover the seed during planting. Therefore, the frequency of tillage during the trial was lower when compared to farmers' common practice. Barley was seeded at the recommended rate of 125 kg ha^{-1}. In the treatment featuring mixed cropping, 37.5% of the normal seed rate of faba bean was mixed intercropped with 100% of the seed rate of barley. The varieties used in the trial were HB-42 for barley and CS20DK for faba bean. The experimental design employed was randomized complete block with three replications and a plot size of 5 m by 8 m (40 m^2). Planting was done in May and harvested in November in both trial seasons.

Crops of the mixed cultures were harvested separately from the whole plot. Grain yield, above-ground biomass, thousand seed weight, number of productive tillers (average of 10 plants, plant height (average of 10 plants) and spike length (average of 10 plants) were recorded. Seeds were weighed and adjusted to constant moisture levels of 12% and 10% for barley and faba bean, respectively. Grain yield of faba bean from the intercropped plot was converted to barley equivalent yield of mixed cropping system using the average price of year 2003 for both crops as follows:

$$EY_{fb} = Y_{fb} \times P_1 / P_2$$

$$EY = Y_b + EY_{fb}$$

Where EY_{fb} is barley equivalent yield of faba bean (kg ha^{-1}), Y_{fb} is yield of faba bean (kg ha^{-1}), P_1 is price of faba bean (ETB 7.16 kg^{-1}), P_2 is price of barley (ETB 3.95 kg^{-1}), EY_i is barley equivalent yield of mixed cropping system (kg ha^{-1}) and Y_b is barley grain yield (kg ha^{-1}).

Soil sampling and analysis

Representative composite soil samples were collected from each trial site in order to carry out proper soil analysis and interpretation. Each composite sample was made of five sub-samples. Finally, the soil analysis data generated were interpreted to illustrate the current soil fertility status of each trial site. The chemical properties of soils in the experimental fields taken before planting and after harvesting barley, which are shown in Tables 1 and 2, were determined using different appropriate analytical procedures in the Soil and Plant Analysis Laboratory of Holetta Agricultural Research Center. Soil reaction (pH) was measured in H_2O with a water-to-soil ratio of 1:1 (Black, 1965). Organic carbon was determined according to the Walkley and Black method (1954). Total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined following the Olsen method (Watanabe and Olsen, 1965). Exchangeable cations and cation-exchange capacity (CEC) were analyzed using the ammonium acetate method (Black, 1965).

Statistical analysis

Analysis of variance was performed using the SAS statistical package program version 9.0 (SAS Institute Inc., 2002). The total variability for each trait was quantified using a pooled analysis of variance over years as per the following model.

$$P_{ijk} = \mu + Y_i + R_{j(i)} + T_k + TY_{(ik)} + e_{ijk}$$

Where P_{ijk} is total observation, μ = grand mean, Y_i = effect of the ith year, $R_{j(i)}$ is effect of the jth replication within the ith year, T_k is effect of the kth treatment, $TY_{(ik)}$ is the interaction of kth treatment with ith year and e_{ijk} is the random error.

Results were presented as means with least significance difference (LSD) at 5% probability level. Correlation coefficients (*r*) were established among agronomic traits using the mean values. In order to assess the effects of treatments on barley growth and yield, seven single degree of freedom orthogonal contrasts were performed using the procedure of SAS.

Results and Discussion

Soil analysis

The soil analysis data was important to identify the level of nutrients in the soil and to determine suitable rates and types of fertilizer for recommendation. The average soil pH of the three trial sites was 6.02, which is moderately acidic and ideal for the production of most field crops. Based on the results obtained for soil analysis, the average total nitrogen (N) and available phosphorus (P) were found to be above the critical levels (Table 1); but not optimal for crop production. These values were 0.23% and 25.33 ppm, respectively, for N and P. Thus, based on the categories of soil characteristics, both nutrient values fall in the medium ranges (Jones, 2003).

The exchangeable cations (EC) and cation exchange capacity (CEC) of the soil were also determined following the standard extraction methods (Table 1). The average contents of potassium (K), calcium (Ca) and magnesium (Mg) in the soil were 1.73, 8.22 and 3.22 Meq/100 g soil, respectively (Table 1). These nutrient values were below the optimum ranges. The average CEC of the soil was also below the critical range, which is 18.86 Meq/100 g soil. The CEC of a soil is the reflection of the status of exchangeable cations (ECs) in the soil. Thus, as the status of ECs decreases, the CEC of the soil also decreases.

Table 1. Average soil analytical results of the trial sites at Degem for samples taken before planting, 2009-2010

Experimental Sites	pH(1:1) H_2O	N (%)	P (ppm)	K	Ca	Mg	CEC	Cu	Zn	Mn
				Meq/100g				ppm		
Elamo-Ferso	6.41	0.22	28	2.71	9.71	2.88	18.89	42.50	37.50	20.00
Anno-Kerre	5.91	0.23	20	1.26	5.64	1.89	16.46	40.00	42.50	17.50
Gende-Sheno	5.75	0.24	28	1.22	9.31	4.89	21.22	37.50	42.50	20.00
Mean	6.02	0.23	25.33	1.73	8.22	3.22	18.86	40.00	40.83	19.17

Though the amount of micronutrients required by plants is small compared to their macronutrient requirements, micronutrients are equally important in limiting the productivity of crops. Accordingly, major micronutrients that are widely associated with such soil types were determined using appropriate extraction methods (Table 1). The soil available micronutrients measured were copper (Cu), zinc (Zn) and manganese (Mn). According to Jones (2003), the critical values of Cu, Zn and Mn are 0.2, 0.6 and 2.0 ppm, respectively. In line with this, the average values measured for these nutrients were 40.0, 40.83 and 19.17 ppm, respectively (Table 1), indicating that the status of these nutrients was at optimum level.

Similarly, representative soil samples were taken from each plot after harvesting. Soil pH values, organic carbon (OC), nitrogen and phosphorus measured for samples taken after harvesting were significantly ($p<0.01$) affected by the application of different soil fertility management options as indicated in Table 2. The highest pH value (5.75) was recorded from 3 t/ha of EM-compost and half doses of the recommended rate of NP fertilizer. The average soil pH of the treatments was about 5.62, which is acidic and requires close supervision for amendment to an optimum level (Table 2). The lowest soil pH (5.18) was recorded from the control plots. In most cases, soil pHs less than 5.5 are supposed to be deficient in Ca, Mg and P (Marschner, 1995; Mengel and Kirby, 1996; Somani, 1996). The exchangeable acidity of such soil determines whether liming is required or not. Though the status of total organic carbon was below the critical level, the highest organic carbon was recorded from plots treated with crop residue and organic and inorganic nutrient sources (Table 2). The average organic carbon content of the experimental soil was 2.76%, which is also categorized in the low range (Jones, 2003). In contrast, the total N and available P determined after harvesting was above the critical range. As noted above for organic carbon, the highest soil N and P were recorded from plots treated with crop residue and organic and inorganic fertilizers (Table 2). The lowest soil N and P contents were obtained from the control plots. In general, the results indicate that integrated use of organic and inorganic nutrient sources including crop residue can result in significant improvement in the overall condition of the soil as well as agricultural productivity if the best alternative option is adopted in the area.

Major causes of nutrient depletion in the area are farming without replenishing nutrients over time, and/or chemical imbalance issues such as soil acidity leading to fixation—often driven by continuous cropping of cereals, removal of crop residues, leaching, low levels of fertilizer usage and unbalanced application of nutrients. In addition, inadequate runoff management can lead to leaching, especially for N and K. Stoorvogel and Smaling (1990) indicated balances of -41 kg/ha N, -6 kg/ha P and -26 kg/ha K in cultivated highland areas of Ethiopia.

Table 2. Mean soil analytical results for the three the trial sites (Elamoferso, Anno-Kerre and Gende-Sheno) at Degem Woreda for samples taken after harvesting, 2009-2010

Treatment	pH	% OC	%N	P (ppm)
Control – No Input	5.18c	2.45d	0.22c	18.60c
50% Straw + 50% NP	5.64ab	2.80b	0.26b	23.13b
100% Compost (6 t/ha)	5.68a	2.81b	0.26b	23.80b
50% Compost + 50% NP	5.72a	2.93a	0.26b	25.20ab
30% Straw + 50% NP + Faba Bean	5.71a	2.84ab	0.28a	25.80ab
50% Straw stubble + 50% NP + Vetch	5.71a	2.82ab	0.27ab	27.40a
50% EM-Compost + 50% NP	5.75a	2.85ab	0.27ab	27.73a
100% Recommended NP	5.58b	2.62c	0.24c	25.53ab
Mean	5.62	2.76	0.26	24.65
LSD (0.05)	0.11	0.12	0.02	2.82
CV (%)	1.7	3.7	3.5	10.0

Means in a column with different letters are significantly different at $p \le 0.05$.

Crop residue production

The amount of crop residue produced from each crop was estimated based on the production of the crop. Crop residue production is a function of biomass production and translocation. Crop biomass production is determined by the biophysical environment and the genetic makeup of the crop (Nordbloom, 1988). More than one-half of all dry matter in the global harvest is in the form of crop residues, and in most developing countries, the amounts of nutrients in crop residues are higher than the quantities applied as fertilizers (IAEA 2001).

However, crop residues are limited given low yields overall, and for some crops, this is exacerbated by off-farm processing (leaves and stems are removed at a central processing facility rather than on-farm). Estimates on availability of crop residues usually depend on harvest indices under research conditions assuming certain field losses (Nordbloom, 1988); an estimate is the product of the total grain production of each crop by its corresponding conversion factor. As indicated in Table 3, the annual production of crop residues in Ethiopia has increased from 6.3 million tons in 1980 to about 31 million tons due to the expansion of cultivated land and increased crop productivity (CSA, 2008). Nordbloom (1988) suggested conversion factors for each crop in east Africa, and these factors were used to estimate annual national crop residue production (Table 3). Crop residue is used for different purposes in the country. Zinash Sileshi and Seyoum Bediye (1989) reported that 63, 20, 10 and 7% of cereal straws are used for feed, fuel, construction and bedding purposes, respectively.

Table 3. National estimate of crop residues produced per annum (based on grain yield of 2007/08)

Residue	Grain production (10^6ton)	Conversion Factor	Crop residue (10^6ton)
Tef	3.0	3.0	9.0
Maize	3.75	2.0	7.5
Wheat	2.38	0.8	1.9
Barley	1.36	1.2	1.63
Sorghum	2.67	3.0	8.0
Millet	0.54	3.0	1.61
Oats	0.04	1.2	0.043
Rice	0.07	0.8	0.057
Pulses	1.78	1.0	1.78
Total	15.59		31.52

Source: Synthesized from Nordbloom (1988) and CSA report (2008)

Yield and yield components

Results showed that yield and yield components of barley were significantly affected by the application of different integrated soil fertility management practices. Barley grain yield, total biomass and harvest index highly significantly ($p < 0.001$) responded to the application of different soil fertility management practices (Table 4). Plant height (average of ten plants), number of productive tillers (NPT) and spike length (SL) significantly ($p < 0.001$) differed as a result of different soil fertility management treatments (Table 4).Thousand grain weight was the only parameter which was not affected by the treatments.

Table 4. Analysis of variance for barley grain yield and other agronomic traits, 2009-2010

Parameters	F-Probability	Root-MSE	Mean
Plant height	0.0003	3.97	88.8
Number of productive tillers (NPT)	0.0001	0.44	4.8
Spike length (SL)	0.0001	0.31	6.1
Total biomass	0.0001	454.73	4263
Grain yield	0.0001	138.86	2134
Harvest index	0.0004	3.96	50.7
1000 seed weight	0.6660	1.67	47.0

The highest barley grain yield (2575 kg/ha) and total biomass (5185 kg/ha) were obtained from the applications of the recommended NP fertilizer rate, followed by 2353 and 5148 kg/ha for grain yield and total biomass, respectively, due to the applications of 3 t/ha EM-compost (inorganic NP fertilizer equivalent) and half doses of the recommended rate of NP fertilizer (Table 5). The grain yield of barley consistently increased as the total biomass increased. Although the highest yields were achieved from the recommended NP fertilizer rate, the other integrated soil fertility management treatments similarly resulted in significant yield advantages compared to the control. In contrast, the highest harvest index (HI) was recorded from the control plot (Table 5).

Yields from the applications of three treatments: half the recommended rate of NP fertilizer plus 3 t/ha conventional compost; retention of 30% of crop residue plus 50% of the recommended rate of NP fertilizer and under-sowing of vetch; and 3 t/ha EM-compost plus 50% of the recommended rate of NP fertilizer were almost indistinguishable. In terms of sustainability, these treatments would have long-term positive and significant impacts on soil and agricultural productivity and greater economic benefits compared to the sole application of inorganic NP fertilizer. A study conducted by Mubarak et al. (2003) indicated that application of half doses of the recommended rate of inorganic fertilizer together with crop residues combined with chicken manure doubled the yield of maize compared to application of only inorganic fertilizer on a maize-groundnut sequence in the humid tropics. Likewise, research findings indicated that the combined use of organic and inorganic nutrient sources improved soil fertility and maize yield (Palm *et al*., 1997; Nzabi *et al*., 1998). Tewodrose Mesfine *et al*. (2005) also reported that the application of 3 t ha^{-1} of tef straw increased grain yield of sorghum by 70% in conventional tillage and by 46% in zero-tillage treatments in the central Rift Valley of Ethiopia. Mean soil water throughout the season was 16% higher with 3 t ha^{-1} application of straw compared to no straw application.

Intercropping of pulses with cereals is among the multiple cropping systems for improving land use efficiency and agricultural productivity. Getachew Agegnehu *et al.* (2006) reported that greater land use efficiency, grain and biomass yield advantages were obtained from mixed intercropping of barley with faba bean as compared to sole cropping of either barley or faba bean.

Table 5. Effect of integrated soil fertility management on yield and yield components of barley in Degem Woreda of North Shewa, 2009-2010

Treatments	Grain yield (kg/ha)	Total biomass (kg/ha)	Harvest index (%)	1000 grain weight (g)
Control – No Input	1497e	2654e	56.7a	47.0
50% Straw stubble +50% NP	1834d	3518d	52.3ab	47.3
100% Compost (6 t/ha)	2036c	3997cd	50.7bc	46.7
50% Compost + 50% NP	2334b	4444bc	54.0ab	47.0
30% Straw stubble +50% NP +Faba Bean	2337b	4755ab	45.7d	46.0
50% Straw stubble + 50% NP + Vetch	2208b	4407bc	50.3bc	46.7
50% EM-compost + 50% NP	2353b	5148a	46.3cd	47.0
100% Recommended NP fertilizer	2575a	5185a	50.0bc	48.0
LSD (0.05)	162.3	531.55	4.63	NS
CV (%)	6.50	10.67	7.8	3.4

Means in a column with different letters are significantly different at $p \leq 0.05$

The findings of Bationo *et al*. (1993) in a West African agro-ecosystem showed that crop residue and mineral fertilizer application has a large positive and additive effect on millet yield as a result of producing higher concentrations of organic carbon. Over the duration of the study, grain yield in control plots (with no fertilizer or crop residue application) were low and steadily declined (Bationo *et al*., 1993). This shows that the potential for continuous millet production on these soils is very limited in the absence of soil amendments. In general, inorganic fertilizer has an immediate benefit, but from a natural resource management point of view, efficient management and utilization of crop residues with other organic nutrient sources and the required inorganic fertilizers in correct balance may contribute to longer-term sustainability of agricultural productivity and an integrated farming system in the highlands of the country, where soil erosion is serious and the resultant soil fertility depletion is high.

The tallest plant height (96.3 cm) was recorded from the application of 30% crop residue, half doses of the recommended NP fertilizer rate and mixed intercropping of 37.5% of the full seed rate of faba bean (75 kg/ha) with the full seed rate of barley. This indicates that the competition between barley and faba bean in the mixture tended to increase barley plant height. Similarly, the findings of Getachew Agegnehu *et al*. (2008) indicated that wheat plant height tended to increase in the mixed culture of wheat and faba bean as compared to sole cropping of wheat. The second largest plant height (92 cm) was recorded with the application of the recommended NP fertilizer rate; while the shortest plant height (85 cm) was recorded from the control plots (Table 6).

Number of productive tillers is one of the most important agronomic parameters to be considered for enhancing productivity. Experimental results showed that the highest number of productive tillers was produced with the application of the recommended NP fertilizer rate, while the second highest number of productive tillers was produced by 3 t/ha of EM-compost plus half doses of the recommended NP fertilizer rate. The maximum average number of productive tillers (6) was produced with the application recommended NP fertilizer rate followed by an average of 5.6 produced from the application of 3 t/ha EM-compost and 50% of the recommended

NP fertilizer rate. The lowest average productive tillers (4.1) were recorded from the control plots (Table 6).

Spike length is among the major yield components of barley that affect its productivity. The largest average spike length (6.7 cm) was obtained from the applications of 3 t/ha EM-compost and half doses of the recommended NP fertilizer rate. The second largest average spike length (6.5 cm) was recorded from two treatments: the application of 3 t/ha compost and half doses of the recommended NP fertilizer; and the retention of 30% of crop residue and half of the recommended rate of NP fertilizer including intercropping of faba bean with barley. The smallest spike length (4.9 cm) was recorded from the control plot (Table 6).

Table 6. Effect of integrated soil fertility management on yield components of barley in Degem Woreda of North Shewa, 2009-2010

Treatments	Plant height (cm)	No. of productive tillers	Spike length (cm)
Control – No Input	85.0c	4.1d	4.9d
50% Straw + 50% NP	87.3c	5.0b	5.9bc
100% Compost (6 t/ha)	86.3c	4.5cd	6.1b
50% Compost + 50% NP	86.0c	4.3cd	6.5a
30% Straw + 50% NP + Faba Bean	96.3a	4.7bc	6.5a
50% Straw + 50% NP + Vetch	88.7bc	4.7bc	6.0b
50% EM-Compost + 50% NP	89.0bc	5.6a	6.7a
100% Recommended NP fertilizer	92.0ab	6.0a	5.7c
LSD (0.05)	4.65	0.52	0.36
CV (%)	4.48	9.0	5.10

Means in a column with different letters are significantly different at $p \le 0.05$

Barley grain yield was significantly positively correlated with total biomass, number of productive tillers, spike size and plant height (Figure 2). Grain yield was most strongly correlated with total biomass (r = 0.94), followed by spike length and number of productive tillers (r = 0.43) and (r = 0.42), respectively. Total biomass was also significantly positively correlated with productive tillers, plant height and spike size; but grain yield was not significantly correlated with harvest index and thousand-grain weight. From these results, it can be inferred that high total biomass, taller plant height and large spike size are the traits associated with good performance of barley. Similar research findings also indicate that grain yield is correlated positively with total biomass and straw yield, spike length, number of productive tillers and plant heights of barley and wheat (Woldeyesus Sinebo, 2002; Getachew Agegnehu and Taye Bekele, 2005).

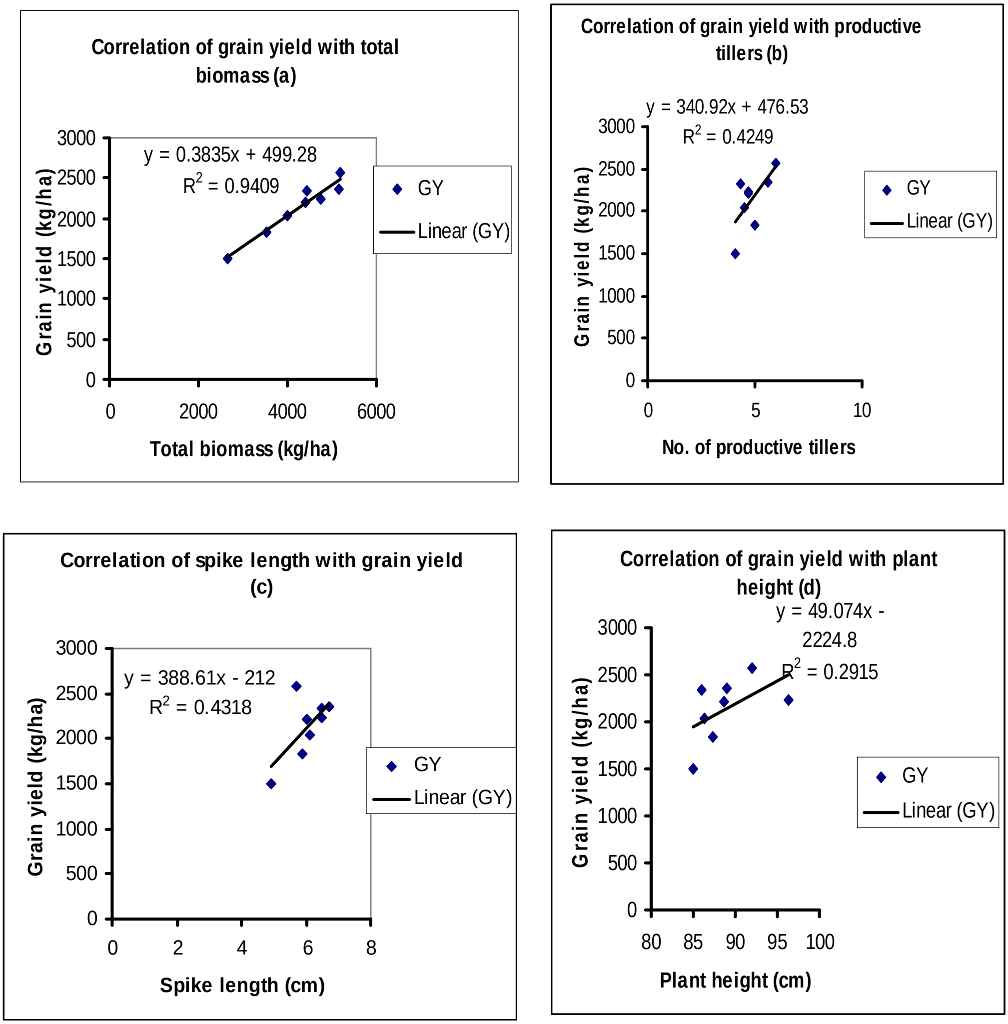

Figure.2. Correlation of barley grain yield with total biomass yield (a), productive tillers (b), spike length (c) and plant height (d).

Partitioning of the treatments into single degrees of freedom orthogonal contrasts revealed that grain yield, total biomass, spike length, productive tillers and plant height of barley significantly differed due to the application of selected integrated soil fertility management treatments (Table 7). The first contrast (control vs. treatment (T) 2-8) had a highly significant ($p < 0.001$) effect on grain yield, total biomass, and spike length and plant height of barley. Nevertheless, this contrast had no significant effect on thousand grain weight. The results showed no significant effect between the contrasts of half doses of the recommended NP fertilizer rate plus 3 t/ha conventional compost (T4) and the other four treatments (T5-T8) on grain yield of barley (Table 7). This clearly indicates that there are no significant differences among four treatments i.e. T4, T5, T6 and T7 on barley grain yield as evidenced in yield data of Table 6.

Getachew Agegnehu and Taye Bekele (2005) also reported similar results on yields of wheat due to the integrated application of nitrogen and phosphorus fertilizers and farmyard manure.

Table 7. Variance ratios and probabilities of variance ratios of single degrees of freedom orthogonal contrasts for different soil fertility management practices

No.	Contrasts	GY†	BY	HI	TGW	PHT	NPT	SL
1	Control vs. treat.2-8							
	Variance ratio	144.32	85.88	15.27	0.00	6.37	22.49	88.40
	F-probability	0.0001	0.0001	0.0004	0.9485	0.0159	0.0001	0.0001
2	T2 vs. (T3-T8)							
	Variance ratio	41.43	25.75	2.74	0.79	1.18	1.51	9.10
	F-probability	0.0001	0.0001	0.1063	0.3796	0.2839	0.2771	0.0045
3	T3 vs. (T4-T8)							
	Variance ratio	15,21	11.09	0.77	0.00	4.08	3.38	6.26
	F-probability	0.0004	0.0019	0.3872	1.0000	0.0505	0.0739	0.0167
4	T4 vs. (T5-T8)							
	Variance ratio	0.02	4.28	10.69	0.01	9.18	25.12	3.20
	F-probability	0.8878	0.0457	0.0023	0.9139	0.0044	0.0001	0.0818
5	T5 vs. (T6-T8)							
	Variance ratio	4.63	0.54	2.97	2.39	11.81	11.91	5.33
	F-probability	0.0378	0.4653	0.0929	0.1303	0.0014	0.0014	0.0265
6	T6 vs. (T7-T8)							
	Variance ratio	13.58	11.15	1.19	0.99	0.85	23.82	1.70
	F-probability	0.0007	0.0019	0.2814	0.3265	0.3624	0.0001	0.1975
7	T7 vs.T8							
	Variance ratio	7.69	0.02	2.57	1.07	1.71	2.51	36.37
	F-probability	0.0086	0.8887	0.1175	0.3081	0.1993	0.1212	0.0001

†GY = Grain yield; BY = Biomass yield; HI = Harvest index; TGW = Thousand grain weight; = Plant height; NPT = Number of productive tillers; SL = Spike length

In general, crop performance did not meet expectations, as the cropping seasons were variable in terms of onset and cessation of rainfall, characterized by the late onset and early termination of rainfall. Nevertheless, the integrated soil fertility management practices proved effective in improving barley production. Though experimental plots treated with crop residue were inferior to others, which may be due to immobilization of nutrients, other research findings indicate that the use of crop residue has multiple effects on improving soil and water resources (Bationo *et al*., 1993; Tewodrose Mesfine *et al*., 2005). It enhances not only soil fertility status by the slow release of nutrients but also conserves soil moisture and protects soil from erosion. Thus, the effects of organic nutrient sources such as crop residue are not as immediate as inorganic nutrient sources, but their effects are long-lasting and sustainable. The results of this experiment are expected to be reproducible in similar agro-ecologies and farming systems of the country.

Poor soil fertility status is currently the main constraint to improve crop yields in Ethiopia. Current indications of poor soil nutrient management across Ethiopia are the frequency of low nutrient reserves in arable soils, negative nutrient balances in cropland and farming practices with few or no external nutrient inputs. Achieving food security for the growing population requires intensifying and sustaining food production on existing cropland through integrated soil fertility management practices that include enhanced nutrient input and recycling. Therefore, appropriate technologies must be developed and implemented to ensure economically viable and ecologically sound nutrient-conserving cropping systems. Since competition for biomass between different uses and users is a major challenge, there is a need to increase biomass in these systems for soil fertility management and other uses. The integrated use of chemical fertilizer and locally available soil amendments is the best approach for achieving higher fertilizer-use efficiency and economic feasibility. If harvested nutrients are replaced, intensive agricultural systems can be sustained, provided that measures are taken to halt soil erosion and to minimize detrimental changes in soil pH. This study suggests use of 3 t/ha compost with half doses of the recommended rate of NP fertilizer can be the best alternative integrated soil fertility management measure in place of the sole application of inorganic fertilizers. Possibly a suggestion for further research would be measuring the longer-term effects of the integrated soil fertility management techniques and the inorganic fertilizer use.

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