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RESEARCH ARTICLE

Influence of integrated soil fertility management in wheat and tef productivity and soil chemical properties in the highland tropical environment

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Abstract

Soil fertility depletion and soil quality decline have been threatening the ecological and economic sustainability of crop production. In order to improve soil fertility and nutrient management approaches, on-farm integrated soil fertility management (ISFM) trials were conducted to evaluate the effects of organic and inorganic fertilizers on wheat (*Triticum estivum* L.) and tef (*Eragrostis tef*) yield and soil fertility in the highland Nitisol area of Ethiopia during 2010 and 2011 cropping seasons. The treatments were five selected combinations of N and P, manure and compost. These included control, farmers' practice (23/10 kg NP ha^{-1}), recommended NP rate (60/20 kg NP ha^{-1}), 50% of recommended NP rate (30/10 NP kg ha^{-1}) + 50% manure and compost as inorganic N equivalence (3.25 tons ha^{-1}). and 50% manure + 50% compost as N equivalence. Results revealed that yields of wheat and tef, and some soil chemical properties significantly responded to the different soil fertility management treatments. The application of 60/20 kg NP ha^{-1} and 30/10 kg NP ha^{-1} with 50% manure and compost as N equivalence increased mean grain yield of wheat by 151 and 129% respectively compared to the control, and by 85 and 68% respectively compared to the farmers' treatment (23/10 kg NP ha^{-1}). Similarly, the same treatments increased tef grain yield by 141 and 122% compared to the control, and by 44 and 33% compared to the farmers' treatment.The application of compost or manure with half the recommended NP fertilizer rate resulted in a comparable yield as that of full NP dose, which could beconsidered as an alternative option for sustainable soil health and crop productivity. In conclusion, the two year result showed that the application of ISFM may optimize yield of wheat and tef as well as improve the fertility status of the soil.

Keywords: Compost, integrated soil fertility management, manure, NP fertilizer, Nitisols, tef, wheat

1. Introduction

Soil fertility decline is the pressing issue in sub-Saharan Africa (Sanchez *et al*. 1997; Bationo *et al*. 2006; Sangingaand Woomer, 2009; Vanlauwe *et al*., 2010). Soil degradation is the most serious bio-physical constraint limiting crop productivity in Ethiopia (FAO, 1998; Zeleke *et al*. 2010). The problem is more serious in the highlands where most of the human and livestock population is found. A recent study has showed that the average annual soil loss from agricultural land is estimated to be 137 tons ha^{-1} per year for the Ethiopian highlands,which is approximately an annual soil depth loss of 10 mm (Spielman *et al*., 2009; Zeleke *et al*., 2010).

In the highlands, long years of cultivation coupled with deforestation and overgrazing with the intention of expanding farmland to meet the needs of the ever-increasing human and livestock population has not only led to severe land degradation and deterioration in the fertility of agricultural soils but also jeopardized the survival of the rural population who depends on agriculture. Studies estimated that cost of land degradation varies between 2-3% of agricultural GDP (Zeleke *et al*., 2010). This is mainly due to the complete removal of crop residues from farm lands, low levels of fertilizer application, use of manure and crop residue as a source of fodder and fuel in place of soil fertility maintenance, lack of appropriate soil conservation practices and cropping systems (FAO, 1998; Elias, 2002; Haileselassie *et al*., 2005; 2006). Thus, the mitigation of soil fertility depletion is currently a pressing issue and major national concern.

Tef (*Eragrostis tef*) and wheat (*Triticum aestivum* L.) are mainly cultivated as mono-crops and usually involved in crop rotations (tef-wheat-food legumes). Wheat and tef show an increasing trend in terms of area coverage, which is about 2.56 and 1.42 million ha, respectively (CSA, 2009). However, their corresponding productivity (1.17 and 1.63 tons ha^{-1}) is very lowdue to poor soil fertility and traditional crop management practices. This is true especially for N and P fertilizers because of continuous cropping of cereals and low level of fertilizer application (Yirga *et al*., 2002; Agegnehu and Bekele, 2005). Moreover, farmers who have the experience and resources to prepare compost often manage to have much less than the amount required.

The most common fertilizers used in Ethiopia are diammonium phosphate (DAP) and urea. Such unbalanced and continuous application of limited fertilizers both in amount and type may aggravate the depletion of other important nutrients such as K, Mg, Ca, S and micro-nutrients not supplied by the chemical fertilizers and may also lead to chemical soil degradation (Dibabe *et al*., 2007). Chemical fertilizers are also costly for farmers to apply the recommended rates. On the other hand, sole application of organic matter is constrained by access to sufficient organic inputs, low nutrient content, high labor demand for preparation and transporting. For instance, the low P content of most organic materials indicates the necessity of external sources of P to sustain crop productivity. Thus, the integration of organic and inorganic sources may improve and sustain crop yields without degrading soil fertility status.

Recent studies have indicated that the interaction effect between combined inputs and practices can provide almost double the crop yield benefits compared to fertilizers applied separately (Agegnehu and Bekele, 2005; Våje, 2007; Dercon and Hill, 2009). For instance, yield gains have been relatively substantial especially for wheat and maize compared to tef when combined with the adoption of optimal farm management practices. In order to improve the resource base 'soil' and crop yield thereby the livelihood of farmers, ISFM project was initiated in 2009. According to Vanlauwe *et al*. (2010, p. 19), ISFM is a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved seed combined with knowledge on how to adapt these practices to local conditions, and aiming to maximize agronomic use efficiency of the applied nutrients and thus crop productivity. It is often believed that ISFM–based crop production systems play important roles in restoring soil fertility and availability of plant nutrients, enhancing crop growth and productivity; they are profitable, socially just, nutrient-dense and resilient (Vanlauwe *et al*., 2010; Zeleke *et al*., 2010). Therefore, the objectives of this experiment were to determine the effects of inorganic and organic fertilizers on soil productivity and crop yield, to adapt innovative approaches to develop ISFM technologies that help alleviate crop production related constraints and incorporate into prototype land-use and production systems of small holder farmers.

2. Materials and Methods

2.1. Experimental set-up and execution

The effects of ISFM were investigated on the yield of wheat and tef under on-farm condition in 2010 and 2011 cropping seasons. After selecting five farms for each crop, the experiments were undertaken on weathered reddish-brown Nitisol areas of Welmera and Addisalem Districts of West Shewa, central highlands of Ethiopia.

The experiment comprised 5 treatments, viz. (i) control - without fertilizer, (ii) farmers' practice (23/10 kg NP ha^{-1}), (iii) recommended NP rate (60/20 kg NP ha^{-1}), (iv) 50% of NP recommended rate (30/10 NP kg ha^{-1}) + 50% manure and compost recommended N equivalence (3.25 tons ha^{-1}), and (v) 50% manure + 50% compost recommended N equivalence (2 tons manure ha^{-1} + 4.5 tons compost ha^{-1}). The design employed was completely randomized block (RCB), and the farmers who hosted the trials were used as replications, where each plot size was 10 m by 10 m.

Manure and compost were prepared following the standard procedure for compost preparation (Inckel *et al*., 2005). Samples were collected from well-decomposed manure and compost before they were applied in the field. Nitrogen and P were analyzed at the soil and plant analysis laboratory of Holetta Agricultural Research Center before the onset of the trial to calculate the mineral fertilizer equivalence using the same analytical procedures that were used for soil. Manure and compost were applied 21 days before sowing and thoroughly mixed in the upper 15-20 cm soil depth. Nitrogen and P fertilizers were applied in the form of urea and DAP respectively. To minimize loss and increase efficiency, N was applied as a split at planting and during the maximum growth period of the crops (tillering stage). Phosphorus was applied at planting. Wheat (var. *HAR-604*) and Tef (var. *Kuncho, DZ-Cross 387*) were planted at the recommended seed rates and sowing dates. Wheat was sown at the rate of 175 kg ha^{-1} in the fourth week of June, and tef at the rate of 25 kg ha^{-1} in mid-July. Other recommended agronomic practices were applied during the crop growth period according to common practices.

2.2. Data collection and analysis

Composite soil samples were collected from each site at 0-30 cm soil depth before treatment application (Table 1) and immediately after harvesting for the analyses of soil pH, total organic carbon (OC), total N, available P, exchangeable K, Na and cation exchange capacity (CEC). Soil reactions (pH) were measured in H_2O with a liquid to solid ratio of 2.5:1. Organic carbon was determined according to Walkley and Black method and total nitrogen using Kjeldahl method. Available phosphorus was determined using the Bray-II method. Exchangeable cations and cation exchange capacity were also analyzed using ammonium acetate method.

Data on grain yield, total biomass, thousand grain weight, harvest index and straw yields of wheat and tef as appropriate were collected. To estimate grain yield and total biomass an area of 6 m by 6 m (36 m^2) was harvested from each plot. Total biomass and grain yields recorded on oven-dry-weight basis were converted to kg/ha for statistical analysis. The SAS statistical computer package (SAS, 2002) was used to test for presence of outliers and normality of residuals. The total variability for each trait was quantified using separate and pooled analysis of variance over years using the following model (Gomez and Gomez, 1984).

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

Where P_{ijk} is total observation, μ = grand mean, Y_i = effect of the i^{th} year, $R_{j(i)}$ is effect of the j^{th} replication (within the i^{th} year), T_k is effect of the k^{th} treatment, $TY_{(ik)}$ is the interaction of k^{th} treatment with i^{th} year and e_{ijk} is the random error. Results were presented as means and least significance difference (LSD) at 5% probability level was used to establish differences among means, and linear regression was performed between grain yield and some relevant yield component parameters for both crops.

Table 1. Soil chemical characteristics of the trial sites before application of treatments

Trial fields	pH	Nitrogen	Phosphorus	OC	Exchangeable cationsmeq/100g		
	(H_2O)	(%)	(ppm)	(%)	Na	K	CEC
Wheat							
1	5.95	0.14	7.00	1.56	0.11	1.97	16.38
2	5.08	0.15	5.80	1.52	0.13	2.25	14.96
3	5.32	0.16	6.20	1.68	0.17	1.55	24.68
4	5.28	0.16	6.40	1.71	0.15	2.11	22.94
Mean	5.41	0.15	6.35	1.61	0.14	1.97	19.74
Tef							
1	4.69	0.14	6.00	1.48	0.11	1.69	17.16
2	4.77	0.16	5.60	1.56	0.11	1.69	15.64
3	5.09	0.15	5.20	1.79	0.11	2.25	14.82
4	5.25	0.18	5.60	1.75	0.19	0.83	22.80
5	5.35	0.18	6.30	1.87	0.17	2.39	27.28
Mean	5.03	0.16	5.74	1.69	0.14	1.77	19.54

3. Results and Discussion

3.1. Effects of organic and inorganic fertilizers on soil chemical properties

Major causes of nutrient depletion in the study 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. The contents of N and P in the analyzed manure before application were 1.54% and 0.41% respectively on 50% dry-weight basis, and 0.72% N and 0.23% P in compost on 55% dry weight basis. Soil analytical data is important to identify the level of nutrients in the soil and to determine suitable rates and types of fertilizers for recommendation. Soil analysis results for samples taken before the applications of treatments were found to be sub-optimal for crop production. The nutrient contents of the soil type used in this study were correspondingly in agreement with the characteristics of the soil identified by farmers as low fertility. As presented in Table 1, the soil pH, total N, OC, available P and the CEC were found to be below the optimum requirement for wheat and tef production. In most cases soils whose pH is less than 5.5 are deficient in Ca, Mg and P (Marschner, 1995; Agegnehu and Sommer, 2000).

Results of soil analysis after harvesting wheat and tef revealed that the application of different soil fertility management treatments significantly ($p < 0.05$ and $p < 0.01$) affected organic carbon, total N, available P, nitrate N (NO_3-N) and ammonium N (NH_4-N) analyzed for samples taken after harvesting from trial fields of both crops. Soil pH of wheat fields was significantly ($p < 0.05$) affected by different soil fertility management treatments, but not soil pH of tef trial sites (Tables 2 and 3). Different soil fertility management treatments had significant effects on post-harvest soil organic carbon content. A significant improvement was observed in organic carbon content compared to the contents of the soil before treatment application.

Relatively higher soil organic carbon was recorded on experimental plots, which received either organic or inorganic and organic nutrient sources (Tables 2 and 3) than plots received only inorganic fertilizers.

Table 2. Effect of different soil fertility management treatments on soil chemical properties after harvesting wheat in the central highlands of Ethiopia

Treatments (kg ha^{-1})	pH (H_2O)	OC (%)	N (%)	P (ppm)	NO_3-N (ppm)	NH_4-N (ppm)
Control	5.57	1.36	0.14	9.40	6.00	8.55b
Farmers NP rate (23/10/0)	5.36	1.61	0.16	11.00	6.33b	9.25
Recommended NP (60/20/0)	5.26	1.83	0.17	15.55	7.20	9.78
50% of recommended NP + 50% manure + 50% compost as N equivalence	5.76	2.06	0.18	15.57	10.60	13.60
50% Manure +50% compost as N equivalence	6.15	1.98	0.17	15.52	9.78	10.70
F-probability (treatment)	*	**	*	**	**	*
$LSD_{0.05}$	0.39	0.21	0.02	3.40	1.82	2.97
CV (%)	4.55	13.20	2.69	16.40	14.81	18.61

*, ** = significant at $p < 0.05$ and $p < 0.01$, respectively; NS = Not significant

Table 3. Effect of different soil fertility management treatments on soil chemical properties after harvesting tef in central Ethiopian highlands

Treatments-N/PK/organic (kg ha^{-1})	pH (H_2O)	OC (%)	N (%	P (ppm)	NO_3-N (ppm)	NH_4-N (ppm)
Control	5.19	1.29	0.17	7.75	6.23	5.93
Farmers NPK rate (23/10/0)	5.05	1.56	0.17	8.40	6.98	7.00
Recommended NPK (60/20/0)	5.33	1.79	0.18	11.85	9.43	8.38
50% of recommended NPK (30/10/0) + 50% manure + 50% compost N equivalence	5.55	2.30	0.19	11.20	10.70	12.90
50% Manure +50% compost as N equivalence	5.48	2.22	0.18	10.25	10.13	8.40
F-probability	NS	**	*	*	*	**
$LSD_{0.05}$	0.31	0.27	0.01	2.73	3.53	3.03
CV (%)	5.76	14.32	3.40	17.93	26.35	23.06

*, ** = significant at $p < 0.05$ and $p < 0.01$, respectively; NS = Not significant

The mean soil pH of wheat trial sites ranges between 5.26 and 6.15, and 5.05 and 5.55 for tef trial sites, which is moderately acidic and in most cases sub-optimal for the production of most field crops. The mean total N and available P were found to be above the critical levels. These values for wheat fields were in ranges of 0.16–0.18% for N and 9.40–15.57 ppm for P, 0.17-0.19% for N and 7.75–11.85 ppm for P for tef fields. Both N and P values were relatively higher for wheat fields than tef trial fields. Nonetheless, based on the categories of soil characteristics, both nutrient values fall in the medium ranges (Jones, 2003). Relatively higher total N, NO_3-N and NH_4-N values were obtained from the plots treated with 50% recommended NP and 50% organic fertilizer as inorganic N equivalence followed by plots treated by 100% manure and compost as recommended inorganic N equivalence (Tables 2 and 3). Significant differences in P values were not observed among inorganic and organic fertilizer treated plots of both wheat and tef fields (Tables 2 and 3). In general, the soil analysis results for samples taken after harvesting revealed that integrated use of organic and inorganic nutrient sources could result in significant improvement in the overall condition of the soil as well as agricultural productivity if the best alternative option is adopted by producers in the area. Kang *et al.* (2005) reported that the long-term application of organic manures in rice/corn–wheat cropping system increased the index value as it increased the nutrient index, microbial index and crop index of soils. Similar research findings also indicated that soils fertilized with manure had higher contents of organic matter (Edmeades, 2003; Srivastava *et al*., 2012) and numbers of micro-fauna than fertilized soils, and were more enriched in P, K, Ca and Mg in top-soils and nitrate N, Ca and Mg in sub-soils (Edmeades, 2003). Agegnehu and Bekele (2005) also reported that the soil pH, total N and organic matter content, CEC and exchangeable cations were significantly improved due to the application of farmyard manure. Haileselassie *et al*. (2006) indicated that N, P and K balances in the wheat based cropping system of central highlands of Ethiopia were -62, -5 and -47kg ha^{-1} respectively, in which based on altitudinal classification the highest nutrient depletion was recorded at foot slopes in Dega, and at the mid-slopes in Woina Dega.

3.2. Productivity of wheat

The combined analysis of variance over two years revealed that the effect of cropping season was highly significant ($p < 0.001$) on total biomass, straw yield and harvest index of wheat and significant ($p < 0.05$) on grain yield. The highest mean grain yield and harvest index of wheat were recorded in 2011 cropping season, implying that the adverse effect of yellow rust disease on wheat in 2010 resulted in a remarkable reduction in grain yield (Table 4). Hence, though grain yield increment trend was observed due to the applications of inorganic and organic nutrient sources the actual yield achieved did not reflect the well growth of wheat in 2010 cropping season due to the incidence of yellow rust disease.

Results indicated that productivity of wheat was significantly affected by different soil fertility treatment levels. Applications of inorganic and organic nutrient sources either alone or in combination had a significant ($p < 0.001$ and $p < 0.01$) effect on grain yield, total biomass and harvest index of wheat, but not on its thousand grain weight. Analysis of variance over two years indicated that the year by soil fertility treatment level interaction (YxT) effect was significant ($p < 0.05$ and $p < 0.001$) for wheat grain yield, total biomass and harvest index; but not for thousand grain weight (Table 4).

Higher wheat grain yield, total biomass and straw yield were obtained from the application of organic and inorganic plant nutrient sources.Yield increases were over 100%, owing to soil fertility status improvement (Table 3). The application of recommended NP at the rate of 60/20 kg NP ha^{-1} increased wheat grain yield by about 151% and 85% compared to the control and the lowest farmers' NP rate respectively. Similarly, application of half the recommended N and P rate and half the recommended rate of manure and compost as inorganic N equivalence resulted in yield advantages of about 129% and 68% compared to the control and the lowest farmers' rate respectively.

Table 4. Response of wheat grain yield (GY), total biomass (TB), straw yield (SY), harvest index (HI) and thousand grain weight (TGW) to ISFM treatments on Nitisols of central Ethiopian highlands

Treatments-N/PK/organic (kg ha^{-1})	GY (kg ha^{-1})	TB (kg ha^{-1})	Straw yield (kg ha^{-1})	HI (%)	TGW (g)
Year					
2010	2286b	6283a	3997a	36.4b	33.9
2011	2466a	5618b	3152b	43.8a	34.7
F-probability	*	***	***	***	NS
$LSD_{0.05}$	144.1	456.8	352.0	2.12	1.60
ISFM-treatments (T)					
Control	1258e	3644d	2387d	34.5bc	35.2
Farmers NPK rate (23/10/0)	1713d	4864c	2932c	35.2b	34.0
Recommended NPK (60/20/0)	3164a	7678a	4514a	41.2ab	33.2
50% of recommended NPK (30/10/0) + 50% manure and compost as N equivalence (3.25 t/ha)	2882b	7073b	4192a	40.8ab	32.9
50% Manure +50% compost (6.5 t/ha) as N equivalence	2646c	6219c	3574b	42.5a	34.9
$LSD_{0.05}$	228.58	679.14	556.6	2.97	2.50
F-probability					
Treatment (T)	0.0001	0.0001	0.0001	0.0001	0.2749
Y × T	*	***	***	***	NS
CV (%)	9.35	11.94	15.41	7.18	7.22

*, *** = significant at $p < 0.05$ and $p < 0.001$, respectively; NS = Not significant. Means in a column with the same letter are not significantly different ($p < 0.05$).

Application of 100% recommended manure and compost as inorganic N equivalence also increased wheat grain yield by 110% and 55% compared to the control that is non-treated plot and farmers' rate of 32/10 kg NP ha^{-1} respectively (Table 4). The results of this study has clearly elucidated that if the application rate of fertilizers either as inorganic, organic or the combination of both is at least doubled under farmers' field condition the yield gain will be more than double compared to the control plot and more than 50% compared to the farmers' applied rate. Furthermore, the study proved the significance of the ISFM treatments containing both organic and inorganic forms under farmers' field condition that they could be considered as alternative options for sustainable soil and crop productivity in the degraded highlands of Ethiopia.

The works of different researchers showed that the integrated application of NP fertilizer with manure resulted in a significant increase in nutrient concentration and uptake, grain and straw yields of wheat (Agegnehu and Bekele, 2005; Matsi *et al.*, 2003; Sharma *et al.*, 1990). The application of manure influences directly the availability of native or applied phosphorus (Sharma *et al*., 1990). It was also found that the application of manure made the soil more porous and pulverised which allows better root growth and development and significantly increased the root CEC at each stage of growth, indicating that its application may prove beneficial for crop nutrition and yield (Sharma *et al*., 1990). Gruhn *et al*. (2000) reported that continuously cropped wheat, without the benefit of organic and inorganic fertilizers, typically has low yields (1.2 tons ha^{-1}). The application of organic and inorganic fertilizers can increase average wheat yields to 6-7 tons ha^{-1}. Wheat yields are highest (9.4 tons ha^{-1}) when farmyard manure is applied, wheat is grown in rotation and inorganic fertilizers are used to top-up N availability (Gruhn *et al*., 2000).

Due to the widespread occurrence of yellow rust disease in 2010, the highest wheat harvest index (43.8%) was recorded in 2011, indicating that better grain yield was also obtained in this season. On the other hand, significantly higher harvest indexes were recorded from the organic and inorganic fertilizer and inorganic fertilizer treatments compared to farmers' practice and control treatments (Table 4). Likewise, despite non-significant differences, the highest thousand grain weight was recorded in 2011. The linear regression analysis revealed that wheat grain yield was significantly positively correlated with total biomass ($R^2 = 0.80$), but weakly correlated with harvest index ($R^2 = 0.18$). Grain yield was most strongly correlated with total biomass (Figure 1). From this result, it can be concluded that high total biomass is the trait associated with good performance of wheat. Similar research findings have also indicated that grain yield is correlated positively with total biomass and straw yield, spike length and number of productive tillers of barley and wheat (Sinebo, 2002; Agegnehu and Bekele, 2005).

3.3. Productivity of tef

Although some of the major limitations of tef production are moisture stress and nutrient deficiencies, mainly of N and P, it performs well on various soil types and diverse agro-ecological zones of the country. The combined analysis of variance over two years revealed that tef positively responded to different soil fertility management treatments. Cropping season had significant effect on straw yield and harvest index of tef, but not on tef grain yield and total biomass indicating that harvest index of tef is sensitive to cropping season. The application of organic and inorganic fertilizers had a highly significant ($p < 0.001$) effect on the total biomass, grain and straw yields of tef. The interaction of cropping season and different soil fertility treatments was not significant (Table 5).

The crop responds well to fertilizer and crop management practices, where the highest tef grain yield was obtained with application of about 60/20 kg NP ha^{-1} on Nitisols of the central Ethiopian highlands. The application of the recommended inorganic NP fertilizer at the rate of 60/20 kg NP ha^{-1} increased tef grain yield and total biomass by about 141% and 149% compared to the control, and 44% and 53% compared to the farmers' NP rate respectively. Application of 50% recommended NP rate and 50% manure and compost as inorganic N equivalence resulted in grain yield and total biomass increments of 122% and 113% compared to the control, and 33% and 31% compared to the farmers' treatment (23/10 kg NP ha^{-1}) (Table 5). A similar trend was observed in the tef grain yield and total biomass due to the application of full dose of manure and compost as inorganic N equivalence. Research findings indicate that growth and yields of tef have responded differently to application of N and P on different soil types (Mamo *et al*., 2001; Ayalew, 2011). For instance, tef has shown a highly significant response to N fertilizer both on Vertisols and Nitisols, but applying N fertilizer beyond the recommended rate may aggravate lodging. In contrast, the response of tef to P has been more important on highly weathered red soils (Nitisols) which fix considerable quantity of applied P than on Vertisols (Mamo *et al*., 2001), which is in agreement with the results of this study. According to these authors a maintenance level of about 10 kg P ha^{-1} could be adequate for tef on Vertisols, which may reach up to 30 kg P ha^{-1} on Nitisols.

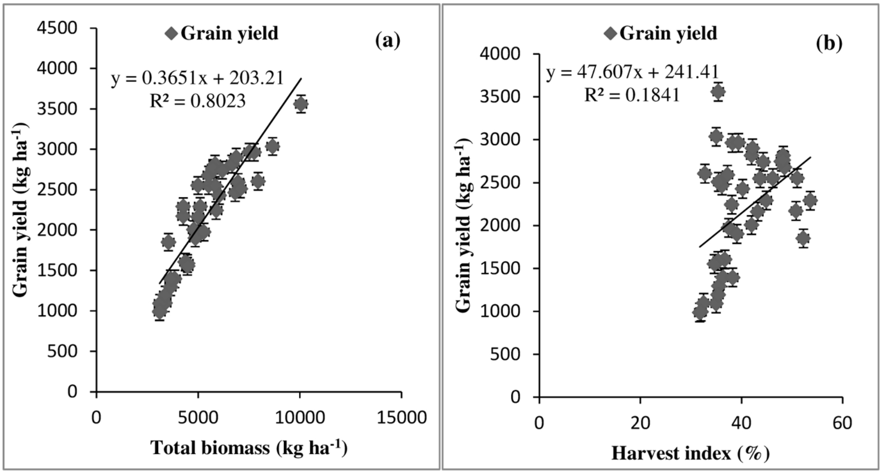

Figure 1. Correlation of wheat grain yield with total biomass (a) and harvest index (b) with standard error bars

The results of this study indicate that there is a potential to increase tef yield through improved soil fertility and crop management practices. This means that the fertility status of soils in the highlands of the country needs to be greatly improved so as to achieve the required output. On station and on-farm research findings indicate that up to 2.5 tons ha^{-1} of tef yield can be obtained under adequate fertilization and improved agronomic practices (Mamo *et al*., 2001), while national average yield is yet about 1.17 tons ha^{-1} (CSA, 2009). Similar results of agronomic trials showed that tef yield can be doubled by the combined use of high yielding varieties and applying both macro-and micro-nutrients such as zinc and copper (Berhe, 2010).

Significantly higher harvest index of tef was recorded in 2010 (Table 5). The harvest index of tef is very low compared to other cereal crops, implying that the total biomass or straw yield of tef is very high compared to its grain yield. In most cases, when the crop performance in terms of growth is high, lodging occurs which could tremendously decrease grain yield of tef. This is also manifested when high N fertilizer is applied and where the soil fertility status is high. The highest harvest index in 2010 is an indication for the clear association between grain yield and total biomass. For instance, the lowest total biomass with the corresponding high grain yield and harvest index was obtained in 2010 compared to high total biomass, but relatively low grain yield and harvest index in 2011 (Table 5). On the other hand, despite numerical differences, there was no statistically significant difference among different soil fertility treatments for harvest index. The highest harvest index was recorded on plots treated with half the recommended inorganic and half with organic fertilizer as inorganic N equivalence. The linear regression analysis showed that tef grain yield was significantly positively correlated with total biomass ($R^2 = 0.84$), but its correlation with tef harvest index was very weak ($R^2 = 0.002$) (Figure 2). From this result, it can be inferred that high total biomass is the trait associated with good performance of tef, but under optimal growth condition and in the absence of lodging that could significantly lower tef grain yield.

Table 5. Response of tef grain yield (GY), total biomass (TB), straw yield (SY) and harvest index (HI) to ISFM treatments on Nitisols of central Ethiopian highlands

Treatments-N/PK/organic ($kg\ ha^{-1}$)	GY ($kg\ ha^{-1}$)	TBY ($kg\ ha^{-1}$)	SY ($kg\ ha^{-1}$))	HI (%)
Year				
2010	1628	5684	4101b	28.6a
2011	1583	6314	4686a	25.8b
F-probability	NS	NS	*	*
$LSD_{0.05}$	134	619	517	2.1
ISFM-treatments (T)				
Control	853d	3232d	2379d	26.4
Farmers NPK rate (23/10/0)	1427c	5250c	3824c	27.2
Recommended NPK (60/20/0)	2057a	8050a	5993a	25.6
50% of recommended NPK (30/10/0) + 50% Manure + 50% compost as N equivalence	1896ab	6895b	4998b	27.5
50% Manure +50% compost as N equivalence	1795b	6567b	4773b	27.3
$LSD_{0.05}$	233	1077	900	3.4
F-probability				
Treatment (T)	***	***	***	NS
Y × T	0.1364	0.7441	0.8122	0.1959
CV	14.2	17.5	19.9	12.0

*, *** = significant at $p < 0.05$ and $p < 0.01$, respectively; NS = Not significant. Means in a column with the same letter are not significantly different ($p \leq 0.05$).

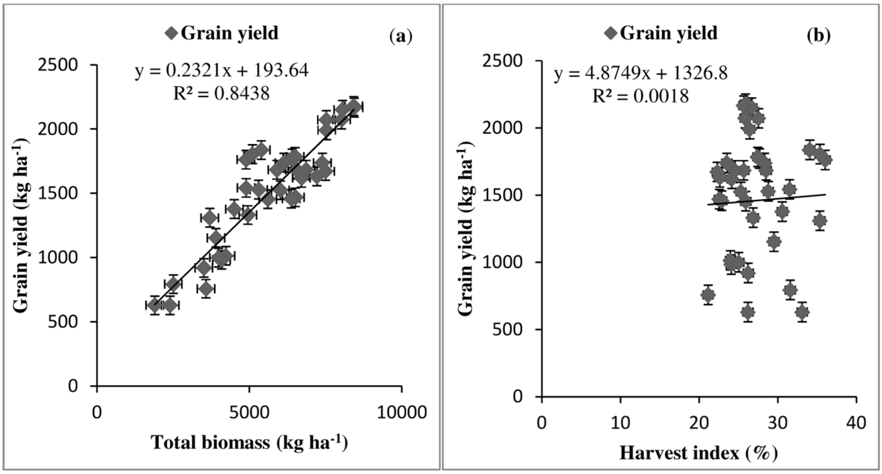

Figure 2. Correlation of tef grain yield with total biomass (a) and harvest index (b) with standard error bars

4. Conclusion

Integrated soil fertility management plays a critical role in both short-term nutrient availability and longer-term maintenance of soil organic matter and sustainability of crop productivity in most smallholder farming systems in the tropics. The two year result showed that the integrated application of organic and inorganic fertilizers improved productivity of wheat and tef as well as the fertility status of the soil. Nevertheless, though ISFM is the notably preferred option in replenishing soil fertility and enhancing productivity, it is not yet widely taken up by farmers. The reasons for this are many, which include access or availability of inputs, use of organic resources for other purposes in place of soil fertility, nutrient balancing, collecting, transporting and management of organic inputs and economic returns of investments. These are the key challenges of adoption in the scaling up of such alternative soil fertility management practices to millions of small-scale farmers in the highlands of the country. There is a need, therefore, for research and extension to sort out issues of adoption and scaling up of the available options. In order to address soil fertility problems, potential synergies can be gained by combining technical options with farmers' knowledge as well as training of farmers and development agent on new soil fertility management approaches.

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