Response of tef (Eragrostis tef (Zucc.). Trotter) to organic and inorganic fertilizers in Ethiopia: Review

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Abstract
Tef [Eragrostis tef (Zucc.) Trotter] is a highly valued crop in the national diet of Ethiopians. It is major crops grown in Central highlands of Ethiopia under wide range of Agro ecological condition. Integrated nutrient management is the best approach to supply adequate and balanced nutrients to increase crop productivity in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. The objective of this review was to investigate the effect of organic and inorganic fertilizers as well as their combination on growth, yield and yield components of tef. Applications of chemical fertilizers mainly Urea and DAP have been started some four decades ago to improve soil fertility for enhanced crop production. Untenable increases in the price of fertilizers coupled with their adverse effects on the soil and reduced recovery efficiency of fertilizers by crops are the bottlenecks that prohibit the indiscriminate use of this technology. On farm using of organic fertilizers is inadequate due to some parts of the country use it as source of energy. Though ISFM is the notably preferred option in replenishing soil fertility and enhancing productivity, it is not yet widely taken up by farmers due to access or availability of inputs, use of organic resources for other purposes in place of soil fertility, transporting and management of organic inputs and economic returns of investments. Therefore, research needs to conduct detailed study on the best combinations of inputs that can boost crop yield in different farming systems and soil types.

Keywords: tef, organic and inorganic fertilizers, integrated soil fertility management, yield

1. Introduction
Tef [Eragrostis tef (Zucc.) Trotter] is a cereal crop that belongs to the grass family Poaceae, which is endemic to Ethiopia and has been widely cultivated in the country for centuries (Teklu and Tefera, 2005). Tef is adaptable to a wide range of ecological conditions in altitudes ranging from near sea level to 3000 m.a.s.l and even it can be grown in an environment unfavorable for most cereal, while the best performance occurs between 1100 and 2950 m.a.s.l in Ethiopia (Hailu and Seyfu, 2000) [41]. It is resistant to extreme water conditions, as it is able to grow under both drought and waterlogged conditions (Minten et al. 2013). In Ethiopia, tef is mainly produced in Amhara and Oromia, with smaller quantities in the Tigray and SNNP regions. East and West Gojam of Amhara and East and West Shoa of Oromia are particularly known tef producing areas in the country (Demeke and Marcantonio, 2013) [18]. During the 2017 meher rains, more than 6.77 million farmers allocated 23.85 percent of the national grain area to tef. The national average tef yield at 2017 reached 1.75 tons ha⁻¹ (CSA, 2017) [16]. Tef is the country’s most important staple crop in terms of both production and consumption, at least in value terms. It is considered as an economically superior good, relatively more consumed by urban and richer consumers (Berhane et al. 2011; Minten et al. 2013). Growth in average incomes and faster urbanization in Ethiopia are likely to increase the demand for tef over time (Berhane et al. 2011). Tef is used to produce the nation’s staple dish enjera, to brew local beer. It has high protein, fiber and complex carbohydrates content, relatively low-calorie content, and is gluten free (Berhane et al. 2011; ATA 2013).

Even though, Ethiopia is a center of origin and diversity of tef and has the above-mentioned importance and coverage of large area, its productivity is very low to feed the demand of its people and market. These is due to low in productivity compared to the potential yield due to lack of adequate synthetic-fertilizer input, limited return of organic residues and manure, and high biomass removal, erosion, and leaching rates, low soil fertility and suboptimal use of...
mineral fertilizers. Although organic inputs, such as farmyard manure and crop residues, are potential sources of plant nutrients and have beneficial effects on soil fertility, there is competition from alternative uses of these resources; both manure and crop residues are used for fuel and crop residues are also used as animal feed and for construction (Abegaz and van Keulen, 2009; Haileselassie et al., 2005) [3, 40]. The continuous removal of biomass (grain and crop residues) from cropland without adequate nutrient replenishment can rapidly deplete the soil nutrient reserves and jeopardize the sustainability of agricultural production (Gete et al., 2010; Getachew et al., 2015) [9, 31]. Nutrients like N, K and P are removed by livestock through grazing and crop residue collection. It is known that among the essential nutrients, both nitrogen and phosphorous are required in large quantities for optimum growth and yield of crop plants. Since Orga-P has lower N concentration (1%) in relation to other nutrients, therefore, there is need to find out the right combination of inorganic N and Orga-P as sources of N and P for optimum yields of tef.

Soil nutrient status is widely constrained by the limited use of inorganic and organic fertilizers and by loss of nutrients mainly due to erosion and leaching (Balesh et al., 2007; Gete et al., 2010; Getachew et al., 2014) [11, 30, 33]. The principle of green revolution in Ethiopia under the blanket recommendation is not successful under most conditions, then more researches has to be done under farmers condition with his own participation in such a manner that the research is able to minimize the different sorts of local problems, by reducing the soil fertility loss and decline in productivity, under what is called the integrated soil fertility management (Abera and Belachew, 2011). Integrated use of 23/20 kg N/P ha−1 with 20 t FYM ha−1 or 46/40 kg N/P ha−1 with 10 t FYM ha−1 are recommended for wheat around Hagarselam, and barley and potato producers around Chencha. The integrated use of 4.53 t FYM ha−1 and 37 kg N ha−1 were recommended for tef production on Vertisols of central highlands (Teklu and Haile Mariam, 2009) [66].

1.1 Objective
To review the effect of compost, farmyard manure, Nitrogen, Phosphorus fertilizers and their interactions in terms of grain yield harvested and to determine the economically optimum inorganic and organic fertilizers rates for tef production.

2. Response of Tef (Eragrostis tef) to organic and inorganic fertilizers
2.1 Growth, yield and yield components of tef in response to organic fertilizers
Organic fertilizers are natural materials of either plant or animal source, including livestock manure, green manures, crop residues, household waste, compost, and works directly as a source of plant nutrients and indirectly influences the physical, biological and chemical properties of soil (Ngoc Son et al; 2004; Basel and Sami, 2014) [12, 54]. Soils fertilized with compost or manure have higher contents of SOM and soil microorganisms than mineral fertilized soils, and are more enriched in P, K, Ca and Mg in the top soil and NO3-N, Ca and Mg in the sub soils (Edmeades, 2003) [19].

2.1.1 Effects of compost on growth, yield and yield components
The use of organic matter such as animal manures, human waste, food wastes, backyard wastes, sewage sludge and composts has long been recognized in agriculture as a beneficial source for plant nutrients and thereby improving, yield of crops. Organic soil amendments (OSA) such as compost produced higher yield of crops because they are the sources of multiple nutrients required by plants or crops for their growth and developments. Organic fertilizers are relatively cheap, technically easy to apply and accessible to all farmers irrespective of their financial capacities (Wassie and Abebe, 2013). Compost is another alternative source of plant nutrients (Ngwira et al., 2013; Odiare et al., 2011; Vanlauwe et al., 2011) [55, 56]. Well-made compost is known to improve soil structure, resulting in improved air exchange, water infiltration and retention (Fischer and Glaser, 2012) [34]. According to Balesh et al. (2007) [11], tef was most responsive to compost on Vertisols and Nitisols. Similarly, Edwards (2006) [60] studied the effects of compost and fertilizer on the yields of seven crops grown in thirty fields in Tigray reported that grain and straw yields of all crops in all fields treated with compost were higher than in control (check) fields Table (1). Accordingly, compost increased the grain yield of crops by 110 and 43% over the control and fertilizer treatments. In addition to higher yield, there is also higher profitability with compost than with fertilizers (Minale et al., 2010).

Table 1: Average yields for seven crops in Tigray, 2001-2005
(Edwards, 2006) [60]

| Crop type                     | Average yield (kg/ha) |
|-------------------------------|-----------------------|
|                               | Check (no input)      | Compost                | Chemical fertilizer |
|                               | Grain straw           | Grain Straw            | Grain Straw         |
| Faba bean                     | 1544                  | 7199                   | 3535                | 13998               | 2696               | 11350               |
| Barley                        | 1661                  | 6927                   | 3535                | 13670               | 1832               | 8269                |
| Wheat (Durum)                 | 1313                  | 6464                   | 2374                | 10740               | 1760               | 8453                |
| Tef                           | 1179                  | 7384                   | 2791                | 12193               | 1774               | 11096               |
| Maize                         | 1843                  | 13545                  | 2401                | 17840               | 3013               | 14363               |
| Mixture of Barley and Durum   | 858                   | 6706                   | 3895                | 10187               | 1199               | 6712                |
| Finger millet                 | 898                   | 4177                   | 2496                | 12148               | 1297               | 6665                |

Adapted from Edwards (2006) [60]

2.1.2 Effects of manure on growth, yield and yield components
In the mixed farming systems of the Ethiopia highlands, farm yard manure (M) is probably the most important soil amendment to which farmers have a better access (Powell et al. 1995) [59]. In addition to its nutrient supply, farmyard manure improves the physicochemical conditions of soils. The beneficial effects of M on crop production through improved soil fertility and physical properties of soil is an established fact. However, unlike the western parts of the country where it is the major means of soil amendment (Teklu et al. 2004), manure is largely used as a source of household energy in the central and the northern parts. Wheat yields are highest (9.4 tons ha−1) when farmyard manure is applied, (Gruhn et al., 2000) [55] and the highest grain yield of wheat was obtained with the application of 6 t M ha−1 and 30 kg N ha−1.

Yield increase due to 60 kg N ha−1 was 300% as compared to the control under no application of manure, but it was only 12.8% when 6 t M ha−1 was applied. This implies that the contribution of 6 t FYM ha−1 to grain yield was comparable to that of 60 kg N ha−1, indicating the possibility of complete substitution of the urea through organic sources (Teklu and Hailemariam 2009) [66]. The marginal rate of return (1-387%) obtained from adopting optimum rate of M and N was higher than the minimum acceptable rate, estimated to be about 50-100% by several studies for farmers already use fertilizers.
(Hailemariam and Gezahegne 2000; Hailemariam et al. 2006; CIMMYT 1988) [38, 39]. According to Teklu and Hailemariam (2009) [40, 41], the economic optimum rate of M and N for wheat (6.85 t M ha\(^{-1}\) and 44 kg N ha\(^{-1}\)) and tef (4.53 t M ha\(^{-1}\) and 37 kg N ha\(^{-1}\)) is less than the agronomic optimum.

2.2 Growth, yield and yield components of tef in response to inorganic fertilizers

2.2.1 Effects of nitrogen on growth, yield and yield components

Tef responds to fertilizers especially to N highly in all its yield components. N is essential for carbohydrate use within plants and stimulates root growth and development as well as uptake of other nutrients (Tisdale et al., 1993; Brady and Weil, 2002) [13, 70]. The acceleration of emergence of the crop in response to N application might be due to the possibility that its supply may have triggered faster germination because of its positive influence on the internal factors regulating the germination process such as increased contents of gibberellic acid in the seed (Taiz and Zeiger, 2006) [64]. A similar result was reported by Temesgen (2012) [68]. On the other hand, this finding is in contrast to Haftom et al. (2009) [37] and Mitiku (2008) [53] who reported that increased application of N delayed emergence in tef. Tef grown at the rate of 46 kg N ha\(^{-1}\) had significantly hastened days to panicle emergence than those grown at the other two higher rates of nitrogen. Similarly, according to finding of Getachew (2004) [31] and Mekonnen (2005) [51], heading was significantly delayed at the highest N fertilizer rate compared to the lowest rate on wheat and barley crops, respectively. According to Fenta Assefa (2018) [23], report, Days to the maturity of tef plants hastened under lower N rates (about 66.5 days by mean at controlled and 66 days at 46 kg ha\(^{-1}\) fertilizer rate than under the higher N (about 70 days treated with 92 kg ha\(^{-1}\) followed by 66.2 days by mean at 69 kg ha\(^{-1}\) N fertilizer rates. Thus, increasing the rate of N from 46 kg ha\(^{-1}\) to 69 kg N ha\(^{-1}\) prolonged days to maturity by about relative short days as compared to that of 92 kg ha\(^{-1}\) N rate, which was very prolonged maturation. This result is in line with the finding of Getachew (2004) [31] and Mekonen (2005) who reported that the heading was significantly delayed at the highest N fertilizer rate compared to the lowest rate on wheat and barley crops, respectively.

Table 2: Main effects of nitrogen fertilizer rates on the phenology of tef

| Nitrogen (kg/ha) | Days to panicle emergence (days) | Days to maturity (days) |
|-----------------|---------------------------------|------------------------|
| 0 kg/ha         | 44.5b                           | 66.5b                  |
| 46 kg/ha        | 43.8b                           | 66.0b                  |
| 69 kg/ha        | 44.7b                           | 66.2b                  |
| 92 kg/ha        | 48.0a                           | 70.0a                  |
| LSD (p<0.05)    | 1.6                             | 1.7                    |

Adapted from Fenta Assefa (2018) [23]

Many studies revealed significant influence of N on plant height as it plays vital role in Vegetative growth of plants. For instance, result reported by Haftom et al. (2009) [37] showed that tef plants with higher plant height (92 cm) and panicle length (38 cm) were found by applying a high amount of N fertilizer (92 kg N ha\(^{-1}\)). This may be attributed to the fact that N usually favors vegetative growth of tef, resulting in higher stature of the plants with greater panicle length. The height obtained from the all treated plots was significantly higher than the unfertilized plot. This is because nitrogen fertilizer has a great role in plant growth. Findings of Legesse (2004) [45], Mitiku (2008) [53] and Haftamu et al. (2009) confirm that panicle length exhibited positive and highly significant correlation with culm length, plant height, number of internodes, and grain yield. Increased application of N caused increased panicle length and hence crops with higher panicle length produced significantly higher total biomass yield, grain yield and straw yield than those with shorter panicles (Giday, 2014) [34].

The number of effective tillers was significantly increased in response to increasing rate of nitrogen fertilizer. The maximum number of effective tillers was recorded in response to nitrogen applied at the rate of 69 kg N ha\(^{-1}\) more effective tillers, but from plots treated with 46 kg N ha\(^{-1}\) the lowest number of effective tillers was obtained. Similarly Legesse (2004) [45], Haftamu et al. (2009) reported significantly higher number of tillers in response to the application of high N rate in tef.

Table 3: Main effects of nitrogen fertilizer rates on the growth parameter of Tef

| Factors N-fertilizer rate | Plant height (cm) | Panicle length (cm) | Effective Tillers |
|---------------------------|-------------------|---------------------|-------------------|
| 0 kgN/ha                  | 57.73d             | 27.42d              | 2.28              |
| 46 kgN/ha                 | 81.82c             | 35.10c              | 2.5               |
| 69 kgN/ha                 | 87.16b             | 36.80b              | 2.67              |
| 92 kgN/ha                 | 92.16a*            | 37.75a              | 2.4               |
| LSD                        | 1.58               | 0.95                | NS                |
| CV (%)                     | 5.39               | 7.46                | 18.77             |

Adapted from Haftamu et al. (2009)

Nitrogen application significantly enhanced biomass yield agrees with the result of Amanuel et al. (1991) [5] who reported a significant increase in biomass yield of wheat because of increased rate of nitrogen application. The application of highest level of nitrogen resulted in less biomass yield (614.8g per plot) compared to 49 kg N ha\(^{-1}\) rate applied in Quncho variety. This might be due to the effect of lodging resulted from too high amount of nitrogen fertilizer that encourage vegetative growth and height leading to lodging before the translocation of dry matter to economic yield since biomass includes the economic yield. According to Mitiku (2008) [53] days to physiological maturity of tef found to be positively correlated with fertilizer application. Studies by Legesse (2004) [45]; Mitiku (2008) [53] and Haftamu et al. (2009) similarly revealed that, further increases in N application resulted in higher total biomass yield.

Table 4: Effect of N rate on yield of tef in vertisols of Gondar Zuria woreda

| N Kg/ha | Year 2014 | Year 2015 | Two years’ combined |
|---------|-----------|-----------|---------------------|
|         | Biomass yield (kg/ha) | Grain yield (kg/ha) | Biomass yield (kg/ha) | Grain yield (kg/ha) | Biomass yield (kg/ha) | Grain yield (kg/ha) |
| 0       | 1343      | 421       | 5404                | 1615               | 3374                | 1018                |
| 46      | 6080      | 1440      | 9019                | 1816               | 7550                | 1789                |
| 69      | 6837      | 1559      | 9561                | 1944               | 8199                | 1751                |
| 92      | 7102      | 1411      | 9576                | 2139               | 8340                | 1613                |
| Mean    | 6673      | 1208      | 8390                | 1879               | 6866                | 1543                |
| LSD     | 855       | 198       | 1116                | 186                | 625                 | 141                 |

Source: International center for agricultural research in the dry areas (ICARDA) www.icarda.org
2.2.2 Effects of phosphorous on growth, yield and yield components

Phosphorus is the main element involved in energy transfer for cellular metabolism in addition to its structural role (Wiedenhoeft, 2006). The number of days required to heading varied among P fertilizer rates. According to result of Getahun et al. (2013) [32], the control (0 P) treatment significantly delayed heading (96.7) while higher levels of P (10, 20 and 30 kg ha\(^{-1}\)), significantly enhanced heading. The reason might be that the applied P fertilizer played an essential role in plant growth and development. Assefa et al. (2016) [36] also reported a similar result. Application of P fertilizer also significantly affected panicle length. The highest panicle length (39.6 cm) was recorded from the application of 20 kg P ha\(^{-1}\) while the shortest was obtained from the control treatment.

The increase in panicle length with increasing P rate could be due to sufficient uptake of P by plants, which encourages plant growth. The result was in agreement with the findings of Giday (2014) [34]. Higher panicle length may have also positive contribution to the grain and straw yields since it has a positive correlation to grain yield. In line with this result, Asefa (2014) [7] reported that the application of balanced fertilizer and efficient utilization of nutrients leads to high photosynthetic productivity and accumulation of high dry matter, which ultimately increases panicle length and grain yield. Onasanya et al. (2009) [83] showed that phosphorus plays an important part in many physiological processes that occur within a developing and maturing plants. It is involved in enzymatic reactions in the plant and hastens the maturity, thus counteracting the effect of excess nitrogen application to the soil. According to Getahun et al. (2018), the shortest days (91.2) to physiological maturity were obtained from the application of 30 kg P ha\(^{-1}\) and the longest days (96.7) from the control. This was due to phosphorus application could possibly shorten maturity date since it promotes rapid cell division and maturity of plants.

Table 5: The main effects of P fertilizer rates on phenology of tef in Asosa and Bambasi 2012-2013

| Treat phosphorus (kg ha\(^{-1}\)) | Days to 50% emergency | Days to 50% heading | Days to 90% physiological maturity | Panicle length (cm) |
|----------------------------------|-----------------------|---------------------|-----------------------------------|---------------------|
| 0                                | 4.2                   | 51.7a               | 96.7a                             | 32.4b               |
| 10                               | 4.3                   | 47.2b               | 92.8b                             | 38.2a               |
| 20                               | 3.9                   | 46.1bc              | 91.4b                             | 39.6a               |
| 30                               | 4.0                   | 45.3c               | 91.2b                             | 38.9a               |
| LSD (5%)                         | Ns                    | 0.92                | 1.83                              | 0.92                |
| CV (%)                           | 25.7                  | 9.2                 | 9.4                               | 11.8                |

Adapted Getahun et al. 2018

According to Fissehaye et al. ([2009] [25] N and P significantly (P</0.01) improved grain yield, biomass yield, height and lodging of plants but not harvest index. The biomass yield of tef was also positively and significantly correlated with P. Although the interaction of N and P was not statistically significant, yet, it was observed that a mixture of N and P gave the highest biomass yield of 3.82 t ha\(^{-1}\) when 69 kg of each of N and P ha\(^{-1}\) was applied. The respective individual yields were 2.45 t ha\(^{-1}\) for N and 1.83 t ha\(^{-1}\) for P at the same rates.

Table 6: Effect of P2O5 rate on yield of tef in vertisols of Gondar Zuria woreda

| P2O5 Kg/ha | Biomass yield (kg/ha) | Grain yield (kg/ha) | Biomass yield (kg/ha) | Grain yield (kg/ha) | Biomass yield (kg/ha) | Grain yield (kg/ha) |
|------------|-----------------------|---------------------|-----------------------|---------------------|-----------------------|---------------------|
| 0          | 3972                  | 860                 | 7508                  | 1674                | 5740                  | 1267                |
| 46         | 5653                  | 1263                | 8223                  | 1891                | 6938                  | 1577                |
| 69         | 5568                  | 1328                | 8871                  | 1947                | 7219                  | 1637                |
| 92         | 6170                  | 1680                | 8958                  | 2001                | 7564                  | 1691                |
| Mean       | 5341                  | 1283                | 8390                  | 1878                | 7240                  | 1543                |
| LSD        | 855                   | 198                 | 1025                  | 186                 | 625                   | 141                 |

Source: Technical report of experimental activities June 2016, International center for agricultural research in the dry areas (ICARDA) www.icarda.org

Table 7: The effect of different levels of P and N fertilizers on tef grain yield (t/ha) and biomass yields (t/ha)

| PKg/ha | 0 | 23 | 46 | 69 | Mean |
|--------|---|----|----|----|------|
| N kg/ha|   |    |    |    |      |
| 0      | 0.51| 0.80| 1.05| 1.25| 0.872 |
| 23     | 0.71| 0.99| 1.12| 1.21| 1.007 |
| 46     | 0.83| 1.21| 1.54| 1.61| 1.299 |
| 69     | 0.91| 1.23| 1.54| 1.63| 1.329 |
| Mean   | 0.73| 1.06| 1.31| 1.39| 1.127 |
| LSD    | 0.10| 0.02| 0.64|    |      |
| CV     | 6.50|    |    |    |      |

Adapted Fissehaye et al. (2009) [25]

2.3 Effect of integrated nutrient application on yield and yield components of tef

A combination of mineral and organic fertilizers is necessary to sustain and improve crop production on depleted soils (Bationo et al., 2006). For sustainable productivity, mixed use of chemical with organic fertilizer has proved to be highly beneficial in terms of balanced nutrient supply (Ali et al.; 2009) (Ayeni and Adetunji, 2010) [10] and significantly higher
than yields from sole organic fertilizer application (Efthimiadou et al, 2010) [20]. The integrated use of 4.53 t ha\(^{-1}\) FYM and 37 kg N ha\(^{-1}\) were recommended for teff production on Vertisols of central highlands (Teklu and Hailemariam, 2009) [60]. The use of 5 t ha\(^{-1}\) of compost either with 55/10 or 25/11 kg of N/P ha\(^{-1}\) is economical for maize production in Bako Tibe district. In another study conducted at Hawassa, Southern Ethiopia, combined use of 23/20 kg N/P ha\(^{-1}\) with 20 t FYM ha\(^{-1}\) or 46/40 kg N/P ha\(^{-1}\) with 10 t FYM ha\(^{-1}\) are recommended for wheat around Hagerselam, and barley and potato producers around Chenga.

According to Girma and Gebreyesus (2013-2014) field experiment conducted for two consecutive cropping seasons on farmers’ fields in Dendi district of Oromia Regional State the highest teff grain and biomass yield 3144.8 kg ha\(^{-1}\) and 12562 kg ha\(^{-1}\) respectively were obtained from the application of 50% VC and half the recommended rate of N and P followed by full dose of recommended rate of N and P from inorganic fertilizer resulting in 2846 kg ha\(^{-1}\) grain and 11833 kg ha\(^{-1}\) biomass yields respectively, where there is no significance differences between the two treatment effects. The application of 50% CC with 50% N and P has also given comparable grain and biomass yield as compared to application of full dose of N and P from inorganic fertilizer. Therefore, the result of study has clearly indicated that it is possible to fairly produce teff through integrated nutrient application approach, rather than applying nutrient from one source. In line with the current result, research findings of Tekalign Ayalew (2011) and Getachew et al. (2012) [27] indicated that tef has showed significance response to 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 productivty in the degraded highlands of Ethiopia.

Work on ISFM has suggested that integrated use of inorganic and organic fertilizers can increase crop yields. Five-year study conducted in the central highlands of Ethiopia found consistently higher yields for treatments that combine half dose of inorganic fertilizer and half dose of organic fertilizer compared to full dose of inorganic or organic fertilizer alone (Workineh et al, 2012). By contrast, in a two-year study on wheat and teff in the highland Nitisol area of Ethiopia, Agegnehu, Vanbeek, and Bird (2014) [50] observed that yields were maintained, but not significantly increased, when 50% of the inorganic fertilizer application was replaced by an N equivalent rate of organic fertilizer.

The use of organic fertilizers together with appropriate chemical fertilizers, had a higher positive effect on microbial biomass and hence soil health (Elkholo et al, 2010, Abedi et al, 2010, Salehi et al, 2017) [2, 2, 61]. Research findings of Tekalign et al. (2001), Ayalew (2011) [19] and Getachew et al. (2012) [27] indicated that tef has showed significance response to 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.

| Treatments                  | PHT (cm) | PL (cm) | BY (kg ha\(^{-1}\)) | GY (kg ha\(^{-1}\)) |
|-----------------------------|----------|---------|---------------------|---------------------|
| Recommended NP              | 114.17   | 42a     | 11833.3ab           | 2846ab              |
| Conventional Compost (CC)   | 98.3     | 39.7abc | 7979.2d             | 1941 de             |
| Farmyard manure (FYM)       | 92.67    | 38.3c   | 8250d               | 1920c               |
| 50% VC + 50% CC             | 101.5    | 40abc   | 8500cd              | 2027cde             |
| 50% VC + 50% FYM            | 103.17   | 40.5abc | 8750cd              | 1933cde             |
| 33% VC + 33% CC + 33% FYM   | 100.83   | 39.1bc  | 9145.8cd            | 2293cd              |
| 50% VC + 50% NP             | 111.5    | 41.17ab | 12562.5a            | 3144.8a             |
| 50% CC + 50% NP             | 108      | 41ab    | 10208.3bc           | 2516.7bc            |
| 50% FYM + 50% NP            | 103.5    | 38.17c  | 9687.5cd            | 2420c               |
| CV (%)                      | 5.12     | 5.6     | 16.6                | 13.9                |

Adapted from Girma and Gurmu (2013-2014)

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Table 9: Response of teff grain yield (GY), total biomass (TB), straw yield (SY) and harvest index (HI) to ISFM treatments on Nitisolso of central Ethiopian highlands

| Treatments                         | GY (kg ha\(^{-1}\)) (\(\times\)1000) | TB (kg ha\(^{-1}\)) (\(\times\)1000) | SY (kg ha\(^{-1}\)) (\(\times\)1000) | HI (%) |
|------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|--------|
| Control                            | 853d                                | 3232d                               | 3824c                               | 27.2   |
| Farmers NPK rate (23/10/0)         | 1427c                               | 5250c                               | 4773b                               | 27.3   |
| Recommended NPK rate (60/20/0)     | 2057a                               | 8050a                               | 5993a                               | 25.6   |
| 50% RNPK (30/10/0) + 50% compost/manure (3.25 t ha\(^{-1}\)) | 1896ab                             | 6895b                               | 4998b                               | 27.5   |
| 50% manure + 50% compost (6.5 t ha\(^{-1}\)) | 1986b                             | 6576b                               | 4773b                               | 27.3   |

Adapted from Getachew Agegnehu (2018)

3. Summery and Conclusion

Ethiopia is one of the 14 sub-Saharan countries with highest rates of nutrient in which, Supplying food for the rapidly increasing population is one of the major problems of today in sub-Ethiopian due to low soil fertility. Soil erosion, continuous cultivation and low nutrient application are the major cause of decline soil fertility in Ethiopia. The continuous removal of biomass (grain and crop residues) from crop land without adequate nutrient replenishment can rapidly deplete the soil nutrient reserves and jeopardize the sustainability of agricultural production. Organic soil amendments (OSA) such as compost produced higher yield of crops because they are the sources of multiple nutrients required by plants or crops for their growth and developments and are relatively cheap, technically easy to apply and accessible to all famers irrespective of their financial capacities. Inorganic fertilizer is usually immediately and fast containing all necessary nutrients that are ready for plants. The excess use of inorganic fertilizers in agriculture can lead
to soil deterioration, soil acidification and environment pollution. The blanket recommendation is not successful under most conditions. So, the ISFM system is an alternative approach for the sustainable and cost-effective management of soil fertility and is characterized by reduced input of inorganic fertilizers. The added benefits obtained from the combined use of compost and NP fertilizer at a reduced application rate suggest that fertilizer and compost should be seen as complementing rather than substituting each other. The integration of organic and inorganic sources can improve and sustain different crop yields without degrading soil fertility status. In this regard, integrated use of N and P and FYM are better than application of either N and P or FYM alone for crop production. Generally, using organic fertilizers in combination with inorganic fertilizers has shortened days to maturity, which is a good strategy to enable the plant to escape terminal moisture stress in rain-fed crop production. 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.

4. Reference
1. Abawi GS, Widmer TL. Impact of soil health management practices on the soil borne pathogens, nematodes and root diseases of vegetable crops. Applied Soil Ecology 2000;15:37-47.
2. Abedi T, Alemzadeh A, Kazemeini S. Effect of Organic and Inorganic Fertilizers on Grain Yield and Protein Banding Pattern of Wheat. Austarlian Journal of Crop Science 2010;4:384-389.
3. Abegaz A, Van Keulen H. Modelling soil nutrient dynamics under alternative farm management practices in the Northern Highlands of Ethiopia. Soil and Tillage Research 2009;103:203-215.
4. Ali ME, Islam MR, Jahiruddin M. Effect of Integrated Use of Organic Manures with Chemical Fertilizers in the Rice-Rice Cropping System and Its Impact on Soil Health. Bangladesh. Journal of Agricultural Sciences 2009;34:81-90.
5. Amanuel Gorfu, Asefa Tana, Tanner DG, Mwangi W. On farm research derive fertilizer recommendations for small scale bread wheat production: Methodological issues and technical results. Research Report No. 14. IAR, Addis Ababa, Ethiopia 1991, 37.
6. Araya H, Edwards S. The Tigray experience: A success story in sustainable agriculture. Environment and Development Series 4, Third World Network, Penang 2006. Available online at http://www.twnside.org.sg/title/end/ed04.htm
7. Asefa F, Debela A, Mohammed M. Evaluation of tef [Eragrostis tef (Zuccagni) Trotter] responses to different rates of NPK along with Zn and B in Dibessa district, southwestern Ethiopia. World Applied Sciences Journal 2014;32:2245-2249.
8. Assefa A, Tamado Tana, Abdulahi J. Effects of Compost and Inorganic NP Rates on Growth, Yield and Yield Components of Tef (Eragrostis tef (Zucc.) Trotter) in Girar Jarso District, Central Highland of Ethiopia. Journal of Fertilizer and Pesticides 2016;7:174. doi:10.4172/2471-2728.1000174
9. Ayalew Abraham. Application of N and P fertilizers for better production of tef on different types of soils in southern Ethiopia. Journal of Natural Sciences Research 2011;1(1):1-11.
10. Ayeni LS, Adetunji MT. Integrated Application of Poultry Manure and Mineral Fertilizer on Soil Chemical Properties, Nutrient Uptake, Yield and Growth Components of Maize. Nature and Science 2010;8:60-67.
11. Balesh Tulema, Aune JB, Breltan TA. Availability of organic nutrient sources and their effects on yield and nutrient recovery of tef and on soil properties. Journal of Plant Nutrition and Soil Science 2007;170:543-550.
12. Basel N, Sami M. Effect of Organic and Inorganic Fertilizers Application on Soil and Cucumber (Cucumis sativa L.) Plant Productivity. International Journal of Agriculture and Forestry 2014;4:166-170.
13. Brady NC, Weil RR. The nature and properties of soil. 13th ed. Person Education Ltd., USA 2002.
14. Channappagoudar BB, Biradar NR, Patil JB, Gasimani CAA. Utilization of weed biomass as an organic source in sorghum. Karnataka Journal of Agricultural Sci 2007;20(2):245-248.
15. Chen JH. The Combined Use of Chemical and Organic Fertilizers and/or Biofertilizer for Crop Growth and Soil Fertility. Taichung, Taiwan 2008.
16. CSA. Central Statistical Agency. Agricultural Sample Survey 2017/18 (2010 E.C.). Report on Area and Production of Major Crops, (Private Peasant Holdings, Meher Season), Statistical Bulletin 584, Addis Ababa, Ethiopia 2017;1.
17. Dakora FD, Keya SO. Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan Africa. Soil Bio/.Biochem 1997;29(5):809-817.
18. Demeke M, Marcantionio F. Analysis of incentives and disincentives for teff in Ethiopia. Technical notes series, FAO, Rome. Density on yield and quality of maize in sandy soil. INS Inet Publication 2013;2(4):156-161.
19. Edmeades DC. The long-term effects of manures and fertilizers on soil productivity and quality: a review. Nutrient Cycling in Agro-ecosystems 2003;66:165-180.
20. Efthimiadou A, Bilalis D, Karkanis A, Williams BF. Combined Organic/Inorganic Fertilization Enhances Soil Quality and Increased Yield, Photosynthesis and Sustainability of Sweet Maize Crop. Australian Journal of Crop Science 2010;4:722-729.
21. Elias E. Farmers' perceptions of soil fertility change and management. ISD and SOKShel International (UK). EDM Printing Press. Addis Ababa, Ethiopia 2002.
22. Elkholy MM, Samira E, Mahrouss, El-Tohamy SA. Integrated Effect of Mineral, Compost and Biofertilizers on Soil Fertility and Tested Crops Productivity. Research Journal of Agriculture and Biological Sciences 2010;5:453-465.
23. Fenta A. Effect of Tef variety and rates of nitrogen fertilizer Application on growth and yield components under jimma condition. Journal of Agricultural and Biological Science 2018;13(3):37-39.
24. Fischer D, Glaser B. Synergism between Compost and Biochar for Sustainable Soil Amelioration, Management of Organic Waste. (S.E. Kumar, ed). In Tech. Shanghai, China 2012, 167-198.
25. Fissehaye Minrute, Mitiku Haile, Fassil Kebede, Alemestay Tsegay, Charles Yamoah. Response of Tef [Eragrostis tef Trotter] to Phosphorus and Nitrogen on a Vertisol at North Ethiopia. Journal of the Dry lands 2009;2(1):8-14.
26. Geremew B. The Role of Integrated Nutrient Management System for Improving Crop Yield and
Enhancing Soil Fertility under Small Holder Farmers in Sub-Saharan Africa: A Review Article. Mod Concept Dev Agrono 2018;2(5).

27. Getachew Agegnehu, Angaw Tsige, Agajie Tesfaye. Evaluation of crop residue retention, compost and inorganic fertilizer application on barley productivity and soil chemical properties in the central Ethiopia highland. Ethiopia. J Agric. Sci. 2012;22:45-61.

28. Getachew Agegnehu, Bekele T. On-farm integrated soil fertility management in wheat on Nitisols of central Ethiopian highlands. Ethiopian Journal of Natural Resources 2005;7:141-155.

29. Getachew Agegnehu, Paul N, Michael IB, Christy Van Beek. Phosphorus Response and fertilizer recommendations for wheat grown on Nitisols in the central Ethiopian highlands. Communications in Soil Science and Plant Analysis 2015;46:2411-2424.

30. Getachew Agegnehu, Van Beek, CM Bird. Influence of integrated soil fertility management in wheat and tet productivity and soil chemical properties in the highland tropical environment. Journal of Soil Science and Plant Nutrition 2014;14:532-545.

31. Getachew Fisseha. Soil characterization and bread wheat (Triticum aestivum L.) response to N and P fertilization (Doctoral dissertation, MSc Thesis, Alemaya University, Alemaya, Ethiopia 2004.

32. Getahun D, Dereje A, Tigist A, Bekele A. Response of Yield and Yield Components of Tef [Eragrostis tef (Zucc.) Trotter] to Optimum Rates of Nitrogen and Phosphorus Fertilizer Rate Application in Assosa Zone, Benishangul Gumuz Region. Ethiop. J Agric. Sci 2013;28(1):81-94.

33. Gete Zeleke, Getachew Agegnehu, Dejene Abera, Shahid Rashid. Fertilizer and Soil Fertility Potential in Ethiopia: Constraints and opportunities for enhancing the system. International Food Policy Research Institute, IFPRI 2010, 63.

34. Giday O, Gibrekidan H, Berhe T. Response of tef (Eragrostis tef) to different rates of slow release and conventional urea fertilizers in vertisols of southern Tigray, Ethiopia. Advances in Plants & Agriculture Research 2014.

35. Gruhn P, Goletti F, Yudelman M. Integrated Nutrient Management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges. Food, Agriculture, and the Environment Discussion Paper 32, International Food Policy Research Institute, Washington D.C., U.S.A 2000, 38.

36. Habte W. Cogent Food and Agriculture 2018;4:1519008. https://doi.org/10.1080/23311932.2018.1519008

37. Haftom G, Mitiku H, Yamoah CH. Tillage intensity, soil compaction and N-fertilizer rate effects on yield of tef (Eragrostis tef (Zucc.) Trotter). Ethiopia Journal of Science 2009;1(1):82-94.

38. Hailiemariam T, Gezahegn A, Tekalign M, Teklu E, Selamyeahun K. Economic optimum of fertilizer use in wheat production in vertisols of central Ethiopia. Ethiopian Journal of Agricultural Economics 2006;6:35-48.

39. Hailiemariam T, Gezahegn A. Economics of fertilizer use on durum wheat. In: The Eleventh Regional Wheat Workshop for Eastern, Central, and Southern Africa. CIMMYT. Addis Ababa, Ethiopia 2000, 395-402.

40. Haileselassie A, Priess J, Veldkamp E, Teketay D, Lesschen JP. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, Ecosystems & Environment 2005;108:1-16.

41. Hailu T, Seyfu K. Production and importance of tef in Ethiopia Agriculture. In: Tefera H, Belay G, Sorrel M (eds.), Narrowing the Rift: Tef research and development-Proceedings of the international Tef Genetics and improvement, 16-19 October 2000, Addis Ababa, Ethiopia 2000.

42. Katovich J, Becker R, Doll J. Weed seed survival in livestock systems. University of Minnesota Extension Services 2005. Available online through http://www.manure.umn.edu/assets/WeedSeedSurvival.pdf

43. Lal R. Soils and food sufficiency. A review. Agronomy for sustainable Development 2009b;29:113-133.

44. Lander, Charles H, David Moffitt, Klaus Alt. “Nutrients available from Livestock Manure Relative to crop Growth Requirements”, U.S. Department of Agriculture, Natural Resources Conservation Service 1998.

45. Legesse A. Response of tef [Eragrostis tef (Zucc.) Trotter] to applied nitrogen and phosphorus in Sirinka North Eastern Ethiopia. MSc Thesis, Alemaya 2004.

46. Liben M, Assefa A, Tadesse T, Marye A. Fertilizer response of tef [Eragrostis tef (Zucc.) Trotter] in the different agro ecologies on Nitosol soils of northwestern Ethiopia, Adet, Ethiopia 2004.

47. Mahmood F, Khan I, Ashraf U, Shahzad T, Hussain S, Shahid M et al. Effects of Organic and Inorganic Manures on Maize and Their Residual Impact on Soil Physico-Chemical Properties. Journal of Soil Science and Plant Nutrition 2017;17:22-22. https://doi.org/10.4067/S0718-95162017005000002

48. Manyong VM, Makinde KO, Sanginda N, Vanlauwe B, Diels J. Fertilizer use and definition of farmer domains for impact-oriented research in the northern Guinea Savanna of Nigeria. Nutrient Cycling in Agroecosystems 2001;59:129-141.

49. Marschner H. Mineral Nutrition of Higher Plants. 2nd ed. Academic Press, London 1995, 783.

50. Matsu T, Lithourgidis AS, Gagianas AA. Effects of injected liquid cattle manure on growth and yield of winter wheat and soil characteristics. Agronomy Journal 2003;95:592-596.

51. Mekonnen A. Response and uptake of barley (Hordeum Vulgare L.) to different Rates of ORG-Pand N fertilizer. MSc Thesis, Alemaya University, Alemaya, Ethiopia 2005.

52. Minale Liben, Alemayehu Assefa, Tilahun Tadesse, Abrham Marye. The Response of Tef to Nitrogen and Phosphorus Applications at Bichena and Yilmana-Densa Areas, Northwestern Ethiopia. CSSSE Tenth Annual Conference, Addis Ababa, Ethiopia 2001.

53. Mitiku Melaku. Effect of Seeding and Nitrogen Rates on Yield and Yield Components of Tef [Eragrostis tef (Zucc.) Trotter] at Adet North Western Ethiopia. M.Sc. Thesis presented to College of Agriculture in Department of Plant Science of Haramaya University 2008, 24-29.

54. Ngoc Son T, Thu V, Hong Man L, Kobayashi H, Yamada R. Effect of Long-Term Application of Organic and Biofertilizer on Soil Fertility under Rice-Soybea Rice Cropping System. OmonRice 2004;12:45-51.

55. Ngwira AR, Nyirenda M, Taylor D. Toward Sustainable
Agriculture: An Evaluation of Compost and Inorganic Fertilizer on Soil Nutrient Status and Productivity of Three Maize Varieties across Multiple Sites in Malawi. Agroecology and Sustainable Food Systems 2013;37:859-881.

56. Odlare M, Arthurson V, Pell M, Svensson K, Nehrenheim E, Abubaker J. Land application of organic waste - Effects on the soil ecosystem. Applied Energy 2011;88:2210-2218.

57. Onasanya R, Aiyelari O, Onasanya An, Oikeh S, Nwilene F, Oyelakin O. Growth and yield response of Maize (Zea mays L.) to different rates of nitrogen and phosphorus fertilizers in southern Nigeria. World J Agri Sci 2009;5:400-407.

58. Onwonga R, Freyer B. Impact of traditional farming practices on nutrient balances in smallholder farming systems of Nakuru District, Kenya. In: Proceeding of the Tropentag - 2006. Prosperity and poverty in a Globalized World - challenges for agricultural research, 11-13 October 2006. Bonn 2006.

59. Powell JM, Fernandez-Rivera S, Williams TO, Renard C. Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Volume II: Technical papers. In: Proceedings of an international Conference held in Addis Ababa, Ethiopia, 22-26 November 1993. ILCA (International Livestock Center for Africa), Addis Ababa, Ethiopia 1995, 558.

60. Redda A, Kebede F. Effects of Integrated Use of Organic and Inorganic Fertilizers on Soil Properties Performance, Using Rice (Oryza sativa L.) as an Indicator Crop in Tselemti District of North-Western Tigray, Ethiopia. International Research Journal of Agricultural Science and Technology 2017;1:6-14.

61. Salehi A, Fallah S, Sourki A. Organic and Inorganic Fertilizer Effect on Soil CO2 Flux, Microbial Biomass, and Growth of Nigella sativa L. International Agrophysics 2017;31:103-116. https://doi.org/10.1515/intag-2016-0032

62. Sewnet Ashebir. Effects of nitrogen and seed rates on grain yield components and nitrogen uptake of rain fed rice (Oryza sativa) in Fogera, South Gondar. A M.Sc. thesis presented to School of Graduate Studies of Alemaya University 2005, 37.

63. Singinga N, Woomer PL. (eds). Integrated soil fertility management in Africa: Principles, practices and development process. Nairobi: Tropical Soil Biology and Fertility Institute of the international Center for Tropical Agriculture 2009, 263.

64. Taiz L, Zeiger E. Plant physiology 4th edition. Sinauer Associates, Inc., Sunderland, MA 2006.

65. Talashiker SC, Rinal OP. Studies on increasing in combination with city solid waste. Journal of Indian Society of Soil Sciences 1986;34:780-784.

66. Teklu Erkossa, Hailemariam Teklewold. Agronomic and Economic Efficiency of Manure and Urea Fertilizers Use on Vertisols in Ethiopian Highlands. Agricultural Sciences in China 2009;8:352-360.

67. Temesgen K. Effect of sowing date and nitrogen fertilization on yield related traits of tef (Eragrostis tef) on vertisols of Kobo area, North Wollo. M.Sc. Thesis presented to Alemaya University 2001, 67.

68. Temesgen K. Response of tef [Eragrostis tef (Zucc.) Trotter] cultivars to nitrogen and phosphorus fertilizer rates at Menzkeya District, North Shewa, Ethiopia. M.Sc. Thesis 2012.

69. Tenaw W. Effect of nitrogen fertilizer rates and plant density on grain yield of maize 2000.

70. Tisdale SL, Nelson WL, Beaton JD, Havlin JL. Soil Fertility and Fertilizers 5th ed. Macmillan publishing company, USA 1993.

71. Vanlauwe B, Diels J, NN, Sanginga N, Merckx R. Long-term integrated soil fertility management in South-western Nigeria: Crop performance and impact on the soil fertility status. Plant and Soil 2005;273:337-354.

72. Wakene Negassa, Kefalew Negisho, Friesen DK, Ransom J, Abebe Yadessa. Determination of optimum Farmyard manure and NP fertilizers for maize on farmer’s fields. In: Friesen, D.K. and Palmer, A.F.E. (Eds.). Proceedings of the Seventh Eastern and Southern African Regional Maize Conference, 5-11 February 2001, Nairobi, Kenya: CIMMYT 2004, 387-393.

73. Wassie H. On Farm Verification of Potassium Fertilizer Effect on the Yield of Irish Potato Grown on Acidic Soils of Hagere Selam, Southern Ethiopia. Ethiopian Journal of Natural Resources 2009;11(2):207-221.

74. Zhao Z, Yan S, Liu F, Ji P, Wang X, Tong Y. Effects of Chemical Fertilizer Combined With Organic Manure on Fuji Apple Quality, Yield and Soil Fertility in Apple Orchard on the Loess Plateau of China. International Journal of Agriculture and Bioengineering 2014;7:45-55.