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SOIL FERTILITY MANAGEMENT STUDIES ON WHEAT IN ETHIOPIA: A REVIEW

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ABSTRACT

This review paper tries to put together soil fertility research based evidences generated over the last two to three decades across the major wheat production belts of Ethiopia. The mean productivity of wheat in farmer's field is about 2.54 t ha^{-1}, in contrast to productivity of over 5 t ha^{-1} achieved on research stations. Research outputs revealed that nitrogen (N) and phosphorus (P) in that order are the two major plant nutrients that limit wheat productivity. The recommendation rates for N and P fertilizers vary from 30-138 N kg ha^{-1} and 0-115 P_2O_5 kg ha^{-1} respectively. These huge differences in NP fertilizer responses across the test locations warrant the need to target the right fertilizer and application rates to the particular location. On the other hand, wheat response to potassium (K) was observed in some test locations contrary to long-standing assumptions that Ethiopian soils are rich in K. Similarly, many researchers noted that micronutrients, i.e. Zn and Cu are severely deficient in many test locations unlike Fe and Mn. Long-term crop rotation trials in different parts of the country also resulted in marked effect on sustainable wheat productivity. Faba bean, field pea, lupine and rapeseed were found the most favorable rotation break crops in most wheat growing areas of Ethiopia. Wheat after legume break crops produced higher grain yields and soil NO_3 than cereal-based rotations and reduced 60-100% of inorganic N fertilizer requirement, levels of root diseases and weed infestations compared to wheat monoculture. The findings of this review indicated that there are viable potentials for increasing the current wheat productivity through improved and available soil fertility management practices.

Key words: Crop rotation, micronutrient, nutrient management, yield

INTRODUCTION

Ethiopia is one of the largest wheat producers in sub-Saharan Africa (Minot et al., 2015; White et al., 2001) with an estimated area of 1.66 million ha and production of 4.3 million tones (CSA, 2016). The area suitable for wheat production falls between 1900 and 2700 m above sea level and is produced exclusively under rainfed conditions (White et al., 2001; Engida Mersha, 2000; Belay Simane et al., 1999). Mean wheat yields increased from 1.3 tons ha^{-1} in 1994 (CSA, 1995) to 2.54 t ha^{-1} in 2015 (CSA, 2016), well below experimental yields of over 5 tons ha^{-1} (Mann and Warner, 2015; Gete Zelleke et al., 2010; Tadesse Dessalegn et al., 2000). However, Ethiopia's current wheat production is insufficient to meet domestic needs, forcing the country to import 30 to 50% to fill the gap (Minot et al., 2015; Dixon et al., 2009; Okalebo et al., 2007). The low yield is primarily allied with the depletion of soil fertility due to continuous nutrient uptake of crops, low fertilizer use and insufficient organic matter application (Kidane Giorgis, 2015; Balesh Tulema, 2005; Taye Bekele et al., 2002; Yesuf Assen and Duga Debele, 2000; Amsal Tarekegn et al., 1997; Asnakew Woldeab et al., 1991).

The yield gap of over 3 tons ha^{-1}, suggests the potential for increasing production through improved soil and crop management practices, particularly increased use of fertilizers and adequate soil fertility maintenance program. Continuous cropping and inadequate replacement of nutrients removed in crop harvest or lose through erosion and leaching has been the major causes of soil fertility decline (van Beek et al., 2016; Hillette Hailu et al., 2015; Adamu Molla, 2013; Chianu and Franklin, 2012; Amsal Tarekegn et al., 2000; Tanner, 1996). This is particularly evident in the intensively cultivated high-potential areas that are mainly concentrated in the highlands of Ethiopia (Hillette Hailu et al., 2015; Chilot Yirga and Mohammed Hassena, 2000; Lakew Desta et al., 2000).

Nutrient balances in the highlands of Ethiopia, typically the high potential areas for agricultural productions are currently exposed to severe nutrient depletion (van Beek et al., 2016). Studies on nutrient cycles in the Central highlands of Ethiopia revealed that the nutrient balance in different soil fertility classes varied from -20 to -185 kg N, from +11 to -83 kg P and from +23 to -245 kg K ha^{-1} yr^{-1} (Balesh Tulema, 2005), and the average annual soil loss from agricultural land is estimated to be 137 tons ha^{-1} yr^{-1}, which is approximately an annual soil depth loss of 10 mm (Gete Zelleke et al., 2010). These indicate that major nutrients outflows far exceed inflows in a range of soil types which results negative nutrient balances. Yet, agricultural production is increasing which benefits farmers' livelihoods and contributes to food security of the country as a whole, but at the expense of the natural resource base (van Beek et al., 2016).

Maintenance of soil fertility at levels which are economically optimal in the long run, given the productive potential of the land as determined by water availability and other climatic factors are essential for sustainable agriculture. With this background, soil fertility management studies have been started in Ethiopia with great emphasis on inorganic fertilizers application mainly Urea and DAP some five decades ago. Earlier wheat soil fertility research achievements in the country were well documented in Asnakew Woldeab et al. (1991) and Tanner et al. (1991). Since 1990s, substantial wheat soil fertility research efforts have been made and comprised of identification of both inorganic and organic inputs and their rates, times and methods of application, crop rotation and multidisciplinary approaches to replenish soil fertility for better wheat productivity. However, their valuable information could not be accessed easily for different users. Therefore, by reviewing research achievements and possibly identifying research and development thrusts for future considerations, this paper has tried to put together essential information of wheat soil fertility studies conducted in Ethiopia in the last two to three decades. Available research outputs, even if they are limited in this review, were gathered from federal and regional agricultural research centers, higher learning institutes and extracted from various published and unpublished research outputs.

METHODOLOGY

Starting point for this review was gathering of the available research outputs from federal and regional agricultural research centers, and higher learning institutes. Personal communications were also conducted to access the published and unpublished research outputs. References were also made to documents of national statistics and progress reports of research centers. Then, a detailed literature search was carried out using web of science, google scholars, AGRIS and open access journals search engines. Papers selection was made through specific searches for appropriate articles on wheat soil fertility studies in Ethiopia in agronomy-soil related peer-reviewed journals, proceedings, books, theses, dissertations, etc. with key words “crop rotation”, “Ethiopia”, “inorganic fertilizer management”, “integrated organic and inorganic nutrient management”, “micronutrients”, “organic fertilizer management”, “soil fertility management” and “wheat”. Whenever peer-reviewed articles related to our synthesis were found in the reference list of an already reviewed article, they were analyzed and included. Selection of research outputs for this review was limited to those published since 1990s. Asnakew Woldeab et al. (1991) and Tanner et al. (1991) documented the earlier ones.

RESULTS AND DISCUSSION

Inorganic fertilizer managements

Wheat grain yield responses to nutrient applications have been agronomically and economically satisfactory in most parts of Ethiopia. Some of the inorganic fertilizer rates (Table 1); timing and source, experimental results that had been tested in different parts of the country are reviewed below.

Application Rates

Fertilizer trials carried out between 1975 and 1990 were conducted on few research stations, and little efforts were made to extrapolate the results to wider range of environments (Amanuel Gorfu et al., 1991). For long National Fertilizer Input Unit (NFIU) recommended 100 kg urea ha^{-1} (46 % N) and 100 kg DAP ha^{-1} (18 % N and 46 % P_2O_5) as blanket fertilizer recommendation in the country was applied despite many criticisms (NFIU, 1992). In 1990s and afterwards, a series of zone-specific, on-farm fertilizer response trials had been conducted by the national wheat research program in collaboration with federal and regional research centers and higher learning institutes aimed at deriving economically optimal N and P recommendations for the predominant wheat varieties in the major wheat producing zones of Ethiopia (Chilot Yirga and Dawit Alemu, 2016; Amanuel Gorfu et al., 1991). The findings suggested that blanket recommendation at national level is not appropriate and so that site specific recommendations would be more beneficial (Tanner *et al.*, 1999).

Table 1: Wheat Responses to inorganic fertilizer applications from selected field trials.

Sources	Soil type	N and P_2O_5 rates (kg ha^{-1})	Responses/ Remark	Area
Abdo Woyema et al., 2012	Vertisols	46-69 N and 46 P_2O_5	Economical	Sinana, South eastern Ethiopia
Abreha Kidanemariam et al., 2013	Humic Cambisols	46 N and 46 P_2O_5	Economical	Tsegede, Northern Ethiopia
Adamu Molla, 2013	Vertisols	101-130.5 N and 23-69 P_2O_5	Economical +ve	Debre Birhan & North Shewa zone, Central Ethiopia
Amsal Tarekegn et al., 1996	Vertisols	60 N and 60 P_2O_5	Economical +ve	Central highlands
Asmare Yallew et al., 1995		92 N and 46 P_2O_5	+ve	East Gojam
Assefa Workineh et al., 2015		138 N and 115 P_2O_5	Economical	Ofla & Alaje, South Tigray
Bekalu Abebe and Mamo Manchore, 2016		69 N and 46 P_2O_5	Economical	Chencha, SNNPR
Bereket Haileselassie et al., 2014		46 N and 46 P_2O_5	Economical	Hawzen, Tigray
Damene Darota, 2003	Haplic Alisol.	69 N and 69 P_2O_5	Economical	Gozo-Bamushi, Dawro Zone
Dawit Habte et al., 2015	Vertisols	92 N and 46 P_2O_5	Economical	Arsi Robe, Digelu-Tijo & Tiyo , Arsi zone, South eastern Ethiopia
Endalkachew Kissi, 2006	Nitosols	69 P_2O_5		Kulumsa, South eastern Ethiopia
Gebreyes Gurmu, 2008	Vertisols	92 N	+ve	Enewari, North Shewa
Genene Gezu, 2003	Eutric Nitosol	90 N and 69 P_2O_5	+ve	Kulumsa, South eastern Ethiopia
Getachew		64 N and 46 P_2O_5	Economical	Central highlands

Sources	Soil type	N and P_2O_5 rates (kg ha^{-1})	Responses/ Remark	Area
Agegnehu and Taye Bekele, 2005				
Haile Deressa et al.,2012		90 - 120 N	Economical +ve	Adaba, South eastern Ethiopia
Kassahun Zewdie, 1996		30 N and no P_2O_5	Economical	Melka Werer, irrigated wheat
Minale Liben et al., 1999	Vertisols	138 N and 46 P_2O_5	Economical +ve	Bichena
Minale Liben et al., 2006		123-138 N and 69 P_2O_5	Economical +ve	Farta & Lai-Gaint, North western Ethiopia
Teklu Erkosa et al., 2000	Vertisols	92 - 115 N and 34.5 P_2O_5	Economical	Akaki & Chefe Donsa, Central Ethiopia
Woldeyesus Sinebo et al., 2012		110 N and 46 P_2O_5	Economical +ve	Hadiya, Kembata-Tembaro, Wolaiyta & Dawro zones
Workneh Negatu and Mwangi, 1994		64 N and 46 P_2O_5	Economical +ve	DebreZeit & Akaki, Central Ethiopia
Worku Awide, 2008	Luvisols, Vertisols	138 N	+ve	Adet & Mota, North western Ethiopia
Yesuf Assen and Duga Debele, 2000a		123 N and 80 P_2O_5	Economical +ve	Eteya-Gonde, South eastern Ethiopia
Yesuf Assen and Duga Debele, 2000a		82 N and 80 P_2O_5	Economical +ve	Bekoji, South eastern Ethiopia

**The amount expressed in P converted into P_2O_5 (P_2O_5= P x 2.29; or P = P_2O_5 x 0.44).*

On-farm trial conducted for three years in the Ada'a and Akaki areas of the central highlands of Ethiopia revealed that application of 64-69 kg N-P_2O_5 ha^{-1} gave statistically significant and economically feasible increase in durum wheat grain yield (Workneh Negatu and Mwangi, 1994). According to Teklu Erkosa (2003), however, the application of 60 kg N ha^{-1} was optimum for durum wheat grown on Vertisols of the central highlands of Ethiopia. Although it did not respond to P fertilizer applications, applying 46 kg P_2O_5 ha^{-1} has been recommended as maintenance fertilization (Teklu Erkosa, 2003).

Gebreyes Gurmu (2008) also reported that in the central highlands, the highest durum wheat mean grain yield was obtained from the maximum N rate (92 kg N ha^{-1}) with an increment of 185 % yield advantage over the control plot, but no significant differences observed for P fertilizer application rates at Enewari, North Shewa zone. The agronomic efficiency (AE) of applied N showed positive response to N fertilizer application which ranged from 12.4 to 18.6 kg grain per kg N

(Gebreyes Gurmu, 2008). Other studies conducted at Sinana in south eastern Ethiopia, showed that application of 46 to 69 kg N ha^{-1} had significant effect on the grain yield (3848 to 4331 kg ha^{-1}) with the advantage of 22 to 31 % over control respectively (Abdo Woyema et al., 2012). In this study, the highest N rates (69 kg N ha^{-1}) resulted in 15 % more grain protein content than the control treatment which is essential for pasta processing and better nutritional value.

A multi-location bread wheat fertilizer response trials conducted on farmers' fields on the poorly drained Vertisols of Bichena in north western Ethiopia indicated an extremely high grain yield response to N and a lesser, but significant response to P (Minale Liben et al., 1999). Bread wheat exhibited a high AE of N response; even at 138 kg N ha^{-1}, AE exceeded 14 kg grain per kg applied N. The highest grain yield, 3317 kg ha^{-1}, was obtained with the application of 138-92 kg N-P_2O_5 ha^{-1}, representing a yield increase of 2336 kg ha^{-1} over the control. ; However, 138-46 kg N-P_2O_5 ha^{-1} was the most economical NP combination for Bichena (Minale Liben et al., 1999). Generally, there was linear increase in all parameters as N and P rates increased. Similarly, fertilizer rates of 138-46 kg N-P_2O_5 ha^{-1} at Farta and 123-46 kg N-P_2O_5 ha^{-1} at Laie-Gaient of North western Ethiopia were also found economically feasible and bread wheat grain yield consistently increased as the rate of applied NP increased to the highest levels (Minale Liben et al., 2006). Similar on-farm experiments conducted in mid-highland Vertisols districts of Arsi zone (Arsi Robe, Digelu-Tijo and Tiyo) revealed that the application of 92-46 N-P_2O_5 kg ha^{-1} gave optimum bread wheat yield with the AE of 13.3 kg grain per kg N applied (Dawit Habte et al., 2015). Endalkachew Kissi (2006) also revealed that application of 30 kg P ha^{-1} significantly increased the grain yield by 0.65 tons ha^{-1} (23.73 %) when compared with the no P application at Kulumsa. Additional recommendations 138-69 and 115-46 N- P_2O_5 kg ha^{-1} were also set for the resource full farmers based on the need to attain the long term high yield goal (Dawit Habte et al., 2015).

The results from the experiment conducted on two soil types in the central highlands of Ethiopia indicated that wheat grain yield increased by 83, 156, 233 and 288 % on Vertisols and by 45, 62, 98 and 150 % on Nitisols in response to the application of 20.5, 41, 82 and 164 kg N ha^{-1} respectively. In similar trends, application of 23, 46 and 92 kg P_2O_5 ha^{-1} resulted in a grain yield increment of 171, 196 and 203 % on Vertisols, and by 71, 90 and 104 % on Nitisols respectively (Table 2). The mean grain yield response to fertilizer application was 163 % on the Vertisols and 76 % on the Nitisols, compared to unfertilized control (Amsal Tarekegn and Tanner, 2001; Amsal Tarekegn et al., 2000b). All wheat N and P uptake parameters exhibited a significant response to both applied N and P with the mean AE of 22.48 and 20.68 kg grain per kg applied N on Vertisols and Nitisols respectively (Amsal Tarekegn and Tanner, 2001). Adamu Molla (2013) also reported that the application of 101-10 kg N-P ha^{-1} and 130-30 kg N-P ha^{-1} are recommended for optimum grain yield on relatively fertile and infertile black soils, respectively, around Debre Birhan, central Ethiopia. Another NP fertilizer rate study at Melka Werer under irrigation indicated that wheat yield significantly increased with the application of 30 kg N ha^{-1}, but not responded to P application, indicating high available P in the soils of Melka Werer (Kassahun Zewdie, 1996).

Table 2. The effects of N and P fertilizer application rates on wheat grain yield grown on Nitisol and Vertisols in central Ethiopia. .

Fertilizer rates	Grain yield (t ha^{-1})	
	Nitosols	Vertisols
N rates (kg N ha^{-1})		
20.5	2.54	1.32
41	2.83	1.84
82	3.46	2.4
164	4.37	2.79
P rates (kg P_2O_5 ha^{-1})		
23	3.00	1.95
46	3.32	2.13
92	3.57	2.18
Control	1.75	0.72
Mean	3.08	1.89
C.V%	16.0	12.8

Source: Amsal Tarekegn et al., *2000b*

In addition, application of 46-46 kg N-P_2O_5 ha^{-1} along with lime was found highly significant as compared to the yield without lime on various parameters on the acidic soils of Tsegede, Northern Ethiopia, which resulted in higher grain yield, total biomass and P uptakes (Abreha Kidanemariam et al., 2013). Related studies at Hossana and Hagereselam in Southern Ethiopia also exhibited that application of lime alone or in combination with 46-92 kg N-P_2O_5 ha^{-1} significantly influenced wheat yield at Hagerselam, but application of lime alone did not affect the wheat grain yield at Hossana (Abay Ayalew et al., 2010). Damene Darota (2003) reported that the application of 69-30 kg N-P ha^{-1} resulted in the highest and economical grain yield at Gozo-Bamushi, Southern Ethiopia.

On the other hand, observational trials on the response of bread wheat to K fertilizer application conducted with different rates (0, 30, 60, 90 and 120 kg K_2O ha^{-1}) at Asassa, Bekoji, Kulumsa and Arsi Robe on stations indicated no significant effect of K fertilizer at all sites with regard to grain yield, clearly indicating that the available K at all locations was sufficient to support plant growth and yield performance (Dawit Habte et al., 2015; KARC, 2007). In contrast, the K fertilizer response trials conducted in acidic soils of Chencha and Hagere Selam, Southern Ethiopia, revealed that the yield of wheat was significantly increased by the application of K fertilizers (Wassie Haile and Tekalign Mamo, 2013). This finding may provide evidences for revising long-standing assumptions that Ethiopian soils are rich in K (Wassie Haile and Tekalign Mamo, 2013).

Methods and Time of NP Fertilizer Application

N is a highly mobile nutrient and when applied to soils it can easily be lost through leaching, volatilization, denitrification and runoff. As a result, the efficiency of applied N in the form of urea is usually less than 50 % (Amanuel Gorfu, 1998). Nitrogen fertilizer rate by timing trials were conducted in southeastern Ethiopia exhibited that the highest grain yield was obtained by application of all N at sowing or split between sowing and tillering than delaying all N application until mid-tillering or later. The grain yield advantages were recorded from 13 to 27 % for the N application at sowing or split between sowing and tillering (Zewdu Yilma and Tanner, 1994). Furthermore, the response to N was the highest for the early application timings, grain yield responses were 8.5 and 7.4 kg grain per kg N over the 0 to 41 kg N ha^{-1} interval respectively. On the other hand, Haile Deressa et al. (2012) revealed that N application of ¼ dose at planting, ½ dose at planting and ¼ dose at anthesis was significantly higher than the grain yield obtained in the N application of ½ dose at planting and ½ dose at mid-tillering and three times of N application with ⅓ dose at planting, ⅓ dose at planting and ⅓ dose at anthesis by about 7.2 and 10.2 %, respectively (Haile Deressa et al., 2012).

Besides, different studies also demonstrated the importance of time of N application to increase grain protein content (Haile Deressa et al., 2012; Genene Gezu, 2003; Yesuf Assen and Duga Debele, 2000b; Asefa Taa et al., 1999) and reduce N losses from the soil-plant system (Amsal Tarekegn and Tanner, 2001) and N available to the plant apparently matched crop needs more closely during the growing period (Haile Deressa et al., 2012; Tilahun Geleto et al., 1996). The general finding showed that split application of N fertilizer (half at planting and the remaining half at tillering or booting stage) had a satisfactory effect on wheat grain yield, particularly in a marginal rainfall zones, severe water logging conditions and at higher N rates (Amare Aleminew et al., 2015; Teklu Erkosa, 2003; Asefa Taa et al., 1997; Zewdu Yilma and Tanner, 1994). In addition yield response to N, N uptake and N-use efficiency improved when high rates of N were applied in split (Amsal Tarekegn and Tanner, 2001; Yesuf Assen and Duga Debele, 2000b).

Another study also examined the effects of three N sources (large granular urea (LGU, 46% N), ammonium sulfate (AS, 21 % N) and standard urea prills), three rates (0, 60 and 120 kg N ha^{-1}), and three different application timings (⅓ at planting and ⅔ at tillering) at Akaki and Robe (Tilahun Geleto et al., 1996). The results revealed that bread wheat responded more to the high rate of N from large granular urea (LGU) or AS than from urea; the maximum grain yield (3.3 tons ha^{-1}) was obtained with 120 kg N from LGU (vs. 2.1 and 2.4 t ha^{-1} with 120 kg N from urea and AS respectively). At low N rate, there was no AE difference among the three N sources, but at 120 kg N ha^{-1}, the AE of LGU was superior to those of urea and AS which did not differ from each other. Apparent N recovery (AR) followed the same trend: at 60 kg N ha^{-1}, N sources exhibited the same level of recovery in grain, but, at 120 kg N ha^{-1}, the AR of LGU was superior to those of urea and AS (Tilahun Geleto et al., 1996).

A trial on the methods of N application at Kulumsa revealed that there was no significant difference between band and foliar methods of N application (KARC, 2001). Another study conducted in similar location to determine the relative effectiveness of three methods of P fertilizer placements (broadcasting, banding to the side of the seeds, and seed dressing by fertilizer P) didn't show significant variations on grain and biomass yields (Endalkachew Kissi, 2006). However, this latter found out that the total P uptake improved from 24.52 kg P ha^{-1} with seed dressing by fertilizer P and broadcasting to 25.81 kg P ha^{-1} with banding P to the side of the seeds.

Micronutrient Studies on Wheat

In most of the nutrient studies in Ethiopia, more emphasis was given to macronutrients, especially N and P, and micronutrients investigations had received little attention. Studies related to the micronutrients status of Ethiopian soils on the other hand are scarce, although the role of micronutrients play in agriculture may be equally important (Yifru Abera and Mesfin Kebede, 2013).

Asgelil Dibabe et al. (2008) documented the status of some micro-nutrients in agriculturally important soils of the country. In their work, Fe and Mn were above critical limit and in some cases Mn surpass the sufficiency level. On the other hand, Zn and Cu were deficient in most zones studied. The frequency of Zn deficiency was highest in Vertisols and Cambisols (78%) and the lowest in Nitisols, whereas Cu deficiency was the highest in Fluvisols and Nitisols with the value of 75 and 69% respectively. In the same study, wheat tissue analysis revealed that no deficiency of Fe and Mn, whereas the deficiency of Zn and Cu were severe, ranging from 43 to 87 % of the total samples analyzed (Table 3). Teklu Baissa et al. (2007) also reported the status of Mn, Zn and B were in sufficient range on Andosols in the rift valley of Ethiopia. Besides, wheat flag leaves micronutrient analysis from ten sites in central highlands Vertisols of Ethiopia showed that Cu, Fe, Mn and Cl- concentrations were within the sufficiency range while Zn was deficient in all of the samples (Hillette Hailu et al., 2015; Amsal Tarekegn et al., 2000a). In addition, recent nutrient survey conducted by EthioSIS exhibited wide spread B and Zn deficiency in the country.

Table 3: Micronutrient contents of wheat collected from different parts of Ethiopia.

Range, mean and percent of deficient samples	Micro-nutrient contents (mg kg^{-1})			
	Fe	Mn	Zn	Cu
Range	0.1-635.6	1.08-255.0	0.1-157.5	0.1-84.3
Mean	121.4	39.2	23.3	3.7
Percent of deficient samples	8.5	80.6	51.6	84.8
Satisfactory level	50-250	55-100	20-70	7-12

Source: Asgelil Dibabe et al., *2008*

Integrated organic and inorganic nutrient management

The use of locally available, nutrient rich organic sources is an effective means for improving soil fertility and increasing crop yield in view of the escalating cost of inorganic fertilizers and low fertilizer use efficiency of crops (Wassie Haile, 2012). Some of the studies conducted to explore alternate organic nutrient sources and partly substitute inorganic fertilizers by biomass transfer, farm yard manure (FYM), compost and green manure.

The effect of *Delicos lablab* as green manure, by ploughing under at flowering stage one month before planting wheat, was studied for two years at Kokate and Hossana, southern Ethiopia. The grain yield due to the application of *Delicos lablab* green manure was similar to that of the yield obtained by application of 46 kg N ha^{-1} (Wassie Haile *et al.*, 2010). The combined applications of *Delicos lablab* and 23 kg N ha^{-1} significantly increased the grain yield by 70 % and 117 % over the control at Kokate and Hossana respectively (Wassie Haile *et al.*, 2010). In the same test locations, a separate study revealed that *Erythrina bruci* biomass (5-10 tons ha^{-1}) incorporated into the soil one month before planting wheat have increased the grain yield by 82-127 % compared to yield received on control plots. Biomass applied at 10 tons ha^{-1} produced grain and straw yields comparable to that produced with the recommended N and P fertilizers (46/40 kg N/P ha^{-1}) for wheat production. Combined applications of 10 t ha^{-1} *Erythrina bruci* biomass + half of the recommended dose of inorganic fertilizers (23/20 kg N/P ha^{-1}) increased grain yield by 173% over the control and gave superior yield than either input applied alone (Wassie Haile, 2012). Chemical analysis of leaf and twig samples of *Erythrina bruci* revealed that it has about 4.83% N, 0.38% P, and 2.24% K (Wassie Haile, 2012).

Evidences showed that application of FYM alone or in combination with inorganic fertilizers enhance proper nutrition and maintenance of soil fertility (Teklu Erkosa and Hailemariam Teklewold, 2009; Balesh Tulema, 2005). Applications of all inorganic fertilizers with or without FYM influenced wheat yield at Hagerselam, Southern Ethiopia. Combined application of 20 tons FYM ha^{-1} with 46 kg N and 40 kg P ha^{-1} gave the highest grain yield of wheat (Wassie Haile et al., 2010). Even if the amounts are huge, Wassie Haile et al. (2010) recommended application of 23 kg N and 20 kg P ha^{-1} with 20 tons FYM ha^{-1} or 46 kg N and 40 kg P ha^{-1} with 10 tons FYM ha^{-1} for farmers around Hagerselam, southern Ethiopia.

On the other hand, application of 6 tons FYM ha^{-1} and 30 kg N ha^{-1} gave the highest wheat grain yield in central highlands of Ethiopia but a comparable result was obtained due to 3 tons FYM ha^{-1} and 30 kg N ha^{-1}. The economic analysis revealed that 6.85 tons FYM ha^{-1} and 44 kg N ha^{-1} for wheat was the economic optimum rates (Teklu Erkosa and Hailemariam Teklewold, 2009). Another experiment conducted on red soils at Holeta indicated that the effect of combined application of inorganic N and P fertilizers and FYM highly significantly increased wheat grain yield (Getachew Agegnehu et al., 2014). The application of 60/20 kg N/P ha^{-1} and 30/10 kg N/P 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 application of 23/10 kg N/P ha^{-1}. In their recent work, Abdi Ahmed et al. (2016) found that despite the highest grain yield achieved with 92 kg N ha^{-1} + 160 kg P_2O_5 ha^{-1} + 20 tons FYM ha^{-1} , application of 92 kg N ha^{-1} + 160 kg P_2O_5 ha^{-1} + 0 FYM ha^{-1} was more economical in Jijiga plain, eastern Ethiopia.

Nigus Demelash et al. (2014) also reported applying 6 tons compost ha^{-1} with 34.5/10 kg N/P ha^{-1} (50 % of the recommended NP) gave a wheat yield increase of 521 %, and followed by 8 tons compost ha^{-1} (442%) and 8 tons compost ha^{-1} (361 %) applied with 34.5/10 kg N/P ha^{-1} over the control, no compost & N-P fertilization (Table 4). The residual effect from 1 year application of compost and inorganic fertilizers also gave yield benefits ranging from 7 to 271 %. This indicates that farmers who cannot afford to apply compost every year could improve productivity by as much as 271 % by applying compost every other year (Nigus Demelash et al., 2014). Another trial conducted at Adet Research Center revealed that wheat after green manure incorporation resulted in significantly higher grain yields. A two-year mean grain yield showed that incorporation of lupine as green manure increased grain yield of wheat more than a green manure vetch (Yeshanew Ashagrie and Asgelil Dibabe, 1999). Mean grain yields of all treatments were significantly higher in the first year than in the second year. A significantly higher yield obtained from lupine-manured plots than vetch-manured and the control plots which gave 1.8 and 1.4 tons ha^{-1} respectively (Yeshanew Ashagrie and Asgelil Dibabe, 1999).

Table 4: The use of compost and inorganic fertilizer on bread wheat in the Gumara-Maksegnit watershed, North Gondar.

Compost* (t ha^{-1})	N-P fertilizer (kg ha^{-1})	Grain yield (kg ha^{-1})
0	0	604
0	17.3-5	1233
0	34.5-10	1538
4	0	1514
4	17.3-5	2381
4	34.5-10	2787
6	0	2057
6	17.3-5	2576
6	34.5-10	3752
8	0	2727
8	17.3-5	2707
8	34.5-10	3279

Source: Nigus Demelash *et al.,* 2014; *The application of 4, 6 and 8 t compost ha^{-1} implies addition of 0.19, 0.29, and 0.38 kg available P ha^{-1}; 40, 60, and 80 kg exchangeable Ca ha^{-1}; 7, 10.5, and 14 kg exchangeable Mg ha^{-1}; 1.9, 2.8, and 3.7 kg exchangeable K ha^{-1}; and 0.8, 1.1, and 1.5 kg exchangeable Na ha^{-1}.

Table 5: Dynamics of Organic carbon, total N and inorganic N contents in the compost during 8.5 months of composting at Adet in 2005-2006.

Trt	Compost composition	Parameters	Composting time (months)					
			Initial	3.5	4.5	6.5	7.5	8.5
1	100% cereal	OC (%)	47.2	46.2	45.5	43.1	39.5	37.9
		Total N (%)	0.71	0.79	0.94	1.24	1.53	1.52
		C/N	66.5	58.5	48.4	34.8	25.8	24.9
		Inorg. N (mg/kg)	-	316	353	496	614	603
2	75% cereal + 25% legume	OC (%)	46.5	44.6	42.5	41.1	38.5	36.3
		Total N (%)	1.05	1.06	1.09	1.32	1.60	1.58
		C/N	44.3	42.1	42.5	31.1	24.1	23.0
		Inorg. N (mg/kg)	-	636	653	793	960	943
3	50% cereal + 50% legume	OC (%)	45.7	44.9	41.5	38.7	36.5	35.8
		Total N (%)	1.33	1.45	1.51	1.57	1.83	1.91
		C/N	34.4	31.0	27.5	24.6	19.9	18.7
		Inorg. N (mg/kg)	-	1454	1498	1544	1682	1497
4	25% cereal + 75% legume	OC (%)	45.0	43.3	40.4	38.2	36.5	34.2
		Total N (%)	1.89	2.01	2.39	2.59	2.67	2.68
		C/N	23.8	21.5	16.9	14.7	13.7	12.8
		Inorg. N (mg/kg)	-	2030	2587	2672	2760	2717
5	100% legume	OC (%)	44.0	42.6	39.4	37.8	34.5	31.6
		Total N (%)	2.03	2.37	2.59	2.67	2.76	2.77
		C/N	21.7	18.0	15.2	14.2	12.5	11.4
		Inorg. N (mg/kg)	-	1949	2582	2617	2757	2683

Source: Yihenew G/Selassie et al., *2010*

Making the best use of available crop residues is an important component of integrated nutrient management. A prominent study conducted at Adet to estimate the inorganic fertilizer equivalent values of compost prepared from different plant materials (cereal straws of *teff*, finger millet, wheat, and legume stubbles of faba bean, field pea and *Sesbania sesban*) and measure the optimal duration required for compost formation. Some data are presented, which showed that composting of 100 % legume stover alone gave the lowest levels of C/N ratio at all composting periods and the desirable level of C/N ratio for application to the soil (below 20) was obtained after 3.5 months of composting (Yihenew G/Selassie et al., 2010). The results clearly indicated that a huge amount of compost is required to obtain equivalent amount of nitrogen that could be obtained from mineral fertilizers (Table 5).

Crop rotation

Another important approach to maintain soil fertility, which has been advocated globally, is the use of improved crop rotation, particularly emphasizing the incorporation of leguminous break crops. Continuous monoculture of wheat or rotation with others cereals is the most common practice in most wheat producing regions of Ethiopia. According to CSA (2016), out of the total grain crop area (12.6 million ha), cereals occupied 80.78 % (10 million ha) of the total cropped land. Pulses occupied only 12.4 % (1.6 million hectares). The short and long-term strategic wheat-based crop rotation trials meant to develop cropping system based nutrient management recommendation and other benefits thereof.

One of the long-term trials, which generated most reliable evidences were conducted at Kulumsa and Asassa research sites in south eastern Ethiopia. Amanuel Gorfu et al. (2000) evaluated the interactions among wheat-based cropping sequences and annual applications of inorganic N and P fertilizers. Rotational crops included rapeseed, faba bean, and barley (Table 6). The results indicated significant rotational effects on wheat grain yield, including enhanced grain yield in dicot vs. cereal rotations. Wheat after faba bean gave the yield advantage of up to 75 % (1.37 tons ha^{-1}) over wheat after wheat (Amanuel Gorfu et al., 2001). Faba bean increased wheat grain yield by 53 % in the first wheat crop and 26% in the second consecutive wheat crop; the corresponding values for rapeseed were 29 % and 12 %. By comparison, the incremental wheat grain yield after barley was only 7 and 5 % for the first and the second wheat crops after barely respectively (Tanner et al., 1999).

Wheat following faba bean gave higher grain yields, but responded lower to applied inorganic fertilizer nitrogen, indicating availability of more N to the wheat crop through atmospheric N_2 fixation by the legume crop (Asefa Taa et al., 1997; Amanuel Gorfu et al., 1996). Wheat-dicot rotations exhibited 35 % higher soil NO_3 levels than cereal-based rotations or continuous wheat production. Wheat-faba bean rotations resulted in a 43 % higher soil NO_3 level than wheat-rapeseed rotations (Amanuel Gorfu et al., 1996). Soil compaction measurement demonstrated that rapeseed plots revealed a lower penetrometer resistance than faba bean plots, reflecting the influence of the rapeseed's characteristic deep tap root on soil structure (Amanuel Gorfu et al., 1996b). Conversely, P response was occasionally enhanced in two year rotations and in the first wheat crop after any break crop, and in dicot-based rotations, particularly with faba bean (Amanuel Gorfu et al., 2000; Asefa Taa et al., 1997).

Comparable results were also documented with similar trials conducted in different part of Ethiopia. Faba bean and Ethiopian mustard increased the mean grain yield of wheat by 59 % vis-à-vis the cereal precursors at Holetta, central Ethiopia (Amsal Tarekegn et al., 1997). At Shambo, western Ethiopia, after a field pea break crop, wheat grain yield was 32 % higher than after barley (Tolera Abera and Mathewos Belissa, 2006). Minale Liben et al. (2001) also confirmed that wheat following lupine significantly out-yielded every other wheat treatment during the three seasons and which exhibited no response to N fertilizer rates at Adet, north western Ethiopia. N fertilizer requirement of wheat as a result of using faba bean and field pea as a precursor crops were reduced to 60 and 80 %, respectively, compared to N requirement of recommended N fertilizer wheat after wheat Eteya-Gonde and Bekoji, South eastern Ethiopia (Table 7). This result demonstrated that as a precursor crop, faba bean contributed more to N requirement of wheat than field pea, for both locations (Yesuf Assen, 2006). Application of 41-46 N- P_2O_5 kg ha^{-1} gave a yield advantage of 16 % over 9-23 N- P_2O_5 kg ha^{-1} at Sinana (Tilahun Geleto et al., 2000) and 56 % increase in soil NO_3 compared to the control at Kulumsa and Asasa, South eastern Ethiopia (Amanuel Gorfu et al., 1996b).

The above reviewed articles exhibited that faba bean, field pea, lupine and rapeseed were the most favorable break crops for wheat production in most wheat growing areas; and wheat grain yield response to fertilizer N was minimal or non-significant after a leguminous break crop, and in the first wheat crop after any precursor crop (Tolera Abera and Mathewos Belissa, 2006; Yesuf Assen, 2006; Amanuel Gorfu et al., 2001; Minale Liben et al., 2001; Tanner et al., 1999).

Table 6: Wheat grain yield (kg ha^{-1}) as affected by crop rotation across five years at Bekoji and Asasa, South eastern Ethiopia

Cropping sequences	Grain yield (kg ha^{-1})	
	Bekoji	Asasa
Fb<u>W</u>	4500	3260
Fb<u>W</u>W	4430	3450
FbW<u>W</u>	3750	2780
Rp<u>W</u>	3800	3000
Rp<u>W</u>W	3770	2870
RpW<u>W</u>	3440	2480
Ba<u>W</u>	3330	2630
Ba<u>W</u>W	3250	2620
BaW<u>W</u>	3230	2410
WWW	3130	2400
Mean	3660	2790
CV (%)	10.9	14.5
LSD (0.005)	389	491

Source: Amanuel Gorfu et al.*, 2000: where: Fb-fababean, W-wheat, Rp-rapeseed, Ba-Barley*

Table 7: Effect of increasing levels of N fertilizer on the grain yield of bread wheat (kg ha^{-1}) at Eteya-Gonde and Bekoji when data combined over years (2000-2002).

N application rate as % of recommended*	Grain yield at Eteya-Gonde		Grain yield at Bekoji	
	After faba bean	After field pea	After faba bean	After field pea
0 %	2707	2424	2336	2102
20 %	3378	3030	3137	2345
40 %	3553	3339	3249	2619
60 %	3983	3527	3544	2664
80 %	3978	3820	3358	3065
100 %	3998	3937	3351	2919
Mean	3599	3346	3162	2619
LSD (0.05)	413	222	195	328
CV (%)	25.6	23.8	24.3	27.9

Source: Yesuf Assen, 2006; *the recommended N rate for Eteya-Gonde and Bekoji were 123 and 82 kg N, ha^{-1}, respectively (Yesuf Assen and Duga Debele, 2000a).

CONCLUSIONS

Low crop productivity and rapid population growth is the main problem facing sub-Saharan Africa in general and Ethiopia in particular. To feed the ever increasing human population and accomplish the increasing demand for agricultural products, agricultural production and productivity must be increased beyond the current level. Therefore, to enhance and sustain agricultural productivity, reducing the degradation of natural resources, improving soil fertility and health management is imperative. In line with, the findings of reviewed research outputs revealed that there are viable potentials for increasing the current wheat productivity through improved and available soil fertility management practices. Implementation of these options in their respective agro-ecologies and soil types can contribute considerably to meet the domestic wheat needs and retain the country's limited foreign currency that is being incurred for importing wheat to fill the gap.

However, still there are many remaining gaps that the future research works should focus on management of soil fertility through balanced crop nutrition that takes account of site-specific deficiencies in macro and micronutrients and considers the use of organic source and other soil amendments is needed to produce yield in excess 4 tons ha^{-1}. In line with this, there is a need to develop fertilizer formulations that address site-specific limiting nutrients based on ISFM principles. Research is needed to further establish crop response patterns and underlying characteristics, and to define the extent of K, S and micronutrient elements limitation to wheat production. Though, integrated use of organic and inorganic nutrient management is very critical and best option to increase crop productivity, mostly it lacks crucial information on the nutrient content and quality of the organic inputs. The available organic resources were usually low quality, reflecting the need to apply large quantities to meet crop nutrient demands. Hence, efforts should continue to find high quality and alternative organic materials. There are no prescriptive guidelines that relate the quality of the organic material to its fertilizer equivalency and its effect on the longer term composition of soil organic matter and crop yields. Comprehensive information on reviewed research outputs was lacking and hardly possible to access them for various uses by different users. Therefore, it is strongly urged to devise mechanisms to national data and agricultural information network.

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