Vol. 17(11), pp. 1433-1452, November, 2021
DOI: 10.5897/AJAR2021.15640
Article Number: 382790568186
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Soil fertility status, fertilizer application and nutrient balance in SNNPR, southern Ethiopia in contrasting agro-ecological zones of Ethiopia

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Received 21 May, 2021; Accepted 28 September, 2021

Soil fertility status evolution is a decision making tool for the sustainable soil nutrient management. To evaluate its status, about 29 research data were collected and meta data analysis were made using SPSS for the selected soil chemical parameters. The soil was moderately acidic and salt free, 93.2% of Zinc (Zn), 100% of Manganese (Mn), 100% of Iron (Fe) and 79.3% of Copper (Cu) status were in sufficient range respectively. However, 44.7% of Phosphorus (P) and 72.3% exchangeable Potassium (K) status were found in a low range, 54.7% of organic carbon (OC) and 34.5% of total nitrogen were respectively found in a medium range, while 93.2% CEC was found in high range. The fertilizer recommendation can be done based on soil fertility status to economize crop production. Land use practices in agro ecosystems and plant species significantly influence the nutrient balance in the soil. According to this review, full nutrient balances of N, P and K in southern Ethiopia, across cropping types were (-31, +71 and -169) respectively. Accordingly, for the better crop production applying recommended fertilizers might be an option to replace the lost nutrients. Major crops (wheat, maize, teff, barley and sorghum) have reveled increased grain yield which were economically positive, indicating the potential of soil in the areas were in deficient levels, hence crops showed responses for fertilizer inputs. Therefore, balanced fertilizer use increase crop production and reduce environmental pollution.

Key words: Crop response, land use, nutrient flow balance, soil fertility status

INTRODUCTION

In the past, soil information in Ethiopia was not available in a comprehensive and coordinated manner, hence no insight was presented to stakeholders (policy makers, small farm holders and others) in a way that respond the question of status and lack of nutrients of the country agricultural lands. Recommendation of site and crop specific fertilizers to increase agricultural production and productivity of Ethiopian farmers was not adequately based on knowledge of nutrient status of the agricultural soils. Therefore, without detailed soil related information

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at specific local level, sustainable crop production could not be achieved. Hence, prior to the recommending any soil management options, soil nutrient supply potential has to be assessed.

Soil characterization in relation to evaluation of fertility status of the soils of an area is an important aspect in the context of sustainable agricultural production (Singh and Mishra, 2012). Periodic assessment of important soil properties and their responses to changes in land management is necessary to apply appropriate soil fertility management techniques, and to improve and maintain fertility and productivity of soil (Negassa and Gebrekidan, 2003).

In case of soil fertility status, land use practices in agro ecosystems and plant species affect the storage of soil organic carbon (SOC) and nitrogen (N). Soil organic matter (SOM) represents a large, dynamic and complex terrestrial reservoir of carbon(C) in the form of organic compounds derived from plant, animal or microbial biomass (Baldock 2009). The rates of C release from the soil vary with land use type, climate and the soil matrix. Several studies have shown that significant amounts of C were lost from the soil as carbon dioxide (CO_2) when forests were converted to agriculture (FAO, 2001) as a result of the release of physically protected soil C (Denef et al. 2007). Despite this loss, agriculture is inevitably required to enhance food security in the developing countries which are threatened by food shortages (FAO 1996).

Thus, identification of soil fertility status in different landscapes is important to draw out information for current and future uses for better crop production. In Ethiopia, the major soil fertility issues are understood only at the higher level with limited information. The widespread blanket fertilizer recommendation rate throughout the country is one indicator of the existence of little information about the fertility status of soils (EthioSIS 2014).

Even, limited studies on fertility status of soils and fertilizer recommendation have been implemented in SNNPR, southern Ethiopia; there is no comprehensive review to document it. In this review some research studies and gap were addressed specially, on fertility status of soils, fertilizer recommendation and crop response in SNNPR, southern Ethiopia.

Therefore, the overall objective of this review is to better understand the fertility status of soils nutrient balance and fertilizer application in SNNPR, southern Ethiopia.

Objectives

General objective

To review and better understand fertility status of soil nutrients, nutrient balance and fertilizer application in SNNPR, southern Ethiopia.

Specific objectives

1) To review and synthesize meta data analysis on fertility status of soil nutrients and soil variability and in SNNPR, southern Ethiopia across contrasting agro-ecological zones.
2) To review nutrient flow and balances in SNNPR, southern Ethiopia across cropping type.
3) To review crop response to fertilizer application and its trend in SNNPR, southern Ethiopia.

MATERIALS AND METHODS

Literature searches were conducted through the Web of Science (apps.webofknowledge.com), Google Scholar (scholar.google.com), AGRIS (agris.fao.org), Research Gate (https://www.researchgate.net), and the Ethiopian Society of Soil Science (www.esss.org.et). Literatures data were collected from published literatures, using "Fertility Status of Soils and Fertilizer Application in SNNPR, Southern Ethiopia in Contrasting Agro-Ecological Zones of Ethiopia" as key words. Several papers were read and data collected, especially focusing reports on "Fertility Status of Soils, nutrient flow and balances in the soil across cropping types, fertilizer trends and crop responses in SNNPR, Southern Ethiopia in Contrasting Agro-Ecological Zones of Ethiopia". To develop this paper, articles were collected and grouped with respect to research objectives. The information collected from the published literatures was organized into Excel. SPSS software was used to performed meta-analysis and graphical presentation.

RESULT AND DISCUSSION

Geographical and socioeconomic description of SNNPR, southern Ethiopia

The Southern Nations, Nationalities and Peoples' Region (SNNPR) is one of the nine regional states of Ethiopia located in the south and south-western part. Geographically it is situated between the coordinates of 4° 27' and 8° 30'N and 34° 21' and 39° 11' E with altitude ranging from 376 to 4207 ma.s.l and with mean annual temperature ranging from 15 to 30°C (BoSP 2004). It covers approximately a total area of 110931.9 km^2 divided into 14 administrative zones and 136 districts. It has very diverse agro-ecology classified as lowlands, mid and highlands covering 57.4, 34 and 8.6% respectively. SNNPR has 13 major and 19 sub-agro-ecological zones (CSA, 2000; Tafesse, 1996; Amare, 1978). Rainfall pattern of the region is bimodal with small rain in dry season and high rainfall in main rain season with mean annual rainfall ranging between 400 mm in the extreme south of *Debub Omo* zone and over 2200 mm in the west in Sheka and Kaffa zones. SNNPR has a total population of 15.04 million of which 89.72% of the people are living in rural areas and 10.28% are urban dwellers (CSA, 2000; Tafesse, 1996).

The population density ranges from 4 to 900 persons per square kilometer. The average land holding size of the region is estimated to be 0.75 ha which lies below the national average (1.2 ha) (CSA, 2010). The region has typical ethnical cultural diversity comprising more than 56 distinct nationalities living in different agro-ecology, all having their own culture, farming system (such as, mixed agriculture, agroforesty and intensive cropping, intercropping and enset and coffee based land use types) that are commonly known in the area, and they have indigenous knowledge of managing natural resources (CSA, 2010; FAO, 2001; BoSP, 2004).

Causes of soil fertility decline in SNNPR, southern Ethiopia

Soil erosion is described as the process of loss of nutrient rich clay and organic matter in rain drop splash, impoverishing the upper top soil and while subsequent erosion peels off the upper soil layers (Miller and Donahue, 1997). In Ethiopia, due to surface topographic condition of most arable lands which concentrates in the highland, the problem of soil erosion is a serious one. In this condition, Ethiopia losses of top soil is about 137 ton per hectare per year (Okigbo, 1986). Loss of macronutrients such as N, P and K in Ethiopia were 122, 13 and 82 kg per hectare per year (Hurni and Bruno, 1990). Even if potentially rich land resources are available in the southern Ethiopia, crop productivity has remained below optimum due to soil erosion, acidity and nutrient depletion, lack of soil fertility replenishment, nutrient mining and lack of balanced fertilization (Amare et al., 2005; Hurni and Bruno, 1990; Tilahun, 2007; Abay et al., 2011; Wassie and Shiferaw, 2011; Bekalu and Mamo, 2016; Awdenegest and Nicholas, 2008; Taye, 2007). Most scholars such Haileslassie et al. (2005), Tilahun (2007) and Wassie and Shiferaw (2011) mentioned that crop yield is directly proportional to nutrient content in the soils.

A study made by Genene and Wagayehu (2010) at Bilate watershed, Southern Ethiopia reported that a higher number of farmers, that is, 84 and 85% of the cases perceived the presence of land degradation and soil erosion in their farm fields respectively. In the highland parts of southern Ethiopia, there is low soil fertility mainly caused by soil erosion (Waga et al., 2007; Smaling et al., 1996; Elias, 2000; Haileslassie et al., 2005). Similarly, according to Waga et al. (2007), erosion is the major cause of soil degradation in SNNPR, southern Ethiopia. Loss of macronutrients such as N, P and K in SNNPR were 64.3, 13 and 48.2 kg per hectare per year (Waga et al., 2007; Smaling et al., 1996; Abay et al., 2011; Haileslassie et al., 2005). In addition to soil erosion by water, soil macronutrient N, P, K depletion was carried out by crop harvest, residual removal, leaching and denitrification (Waga et al., 2007; Smaling the negative nutrient balances emphasizing the need for improved soil and water conservation measures at farm level and at catchment level. Soil fertility is declining particularly in densely populated and hilly country parts in case of southern Ethiopia (Sanchez et al., 2000; Haileslassie et al., 2005; Wassie and Shiferaw, 2011).

Fertility status of soil nutrients and soil variation across different locations in SNNPR, Ethiopia

In Ethiopia, agriculture is the mainstay of the majority of the population and major driver of the national economy. Agricultural production has been highly dependent on natural resources for centuries (Amsalu et al., 2007). However, increased human population and other factors have degraded the natural resources in the country, thus seriously threatening sustainable agriculture and food security (Tsegaye and Bekele, 2010). Continuous cropping and inadequate replacement of nutrients removed in harvested materials or lost through erosion and leaching has been the major causes of soil fertility decline (Matson and Naylor, 1998). This is particularly evident in the intensively cultivated areas, traditionally called high-potential areas that are mainly concentrated in the highlands of Ethiopia.

Soil nutrient depletion in smallholder farming systems is recognized as a causal force leading to food insecurity and rural poverty in Sub-Saharan Africa (SSA) (FAO, 2001). In Ethiopia, the depletion rate of macronutrients: 122 kg N per hectare per year, 13 kg P per hectare per year and 82 kg K per hectare per year, was estimated to be high (Haileslassie et al., 2005). Decline in soil fertility has also been stressed to be the fundamental obstacle to agricultural development and the major reason for the slow growth in food production in Ethiopia (Asfaw et al., 1997). Blanket recommendation of fertilizer and loss of nutrients by different factors such as soil erosion, plant uptake, removal of residual and land degradation are serious problem in case of SNNP, southern Ethiopia (Wondwosen and Sheleme, 2011; Tilahun, 2007). To alleviate such problem, there are good reasons to begin with EthioSIS, to recommend fertilizer in site specific manner that might help to recover loss of nutrients in the soil.

The findings indicated that different soil fertility management is very essential to enhance crop productivity. This is because different soil types exhibit varying characteristics due to differences in micro-morphological, morphological, physical, chemical and mineralogical properties. Variations in soil forming factors and processes operating on different parent materials, under different climatic, topographic, and biological conditions over varying periods would cause these variations. Therefore, their nutrient potential of soils also directly related to the pedogenic processes and other human management practices both negatively and positively. In this section the review highlighted both nutrient status of soils based on their potential across land use types and the different values for the various soil fertility parameters critical levels which were rated by the EthioSIS (EthioSIS, 2014) as shown in Tables 1 and 2, Annex 1).

Based on analyzed meta data (Annex 1) the geographical distribution of the soil types was determined with the aid of land systems, area with specific and unique geomorphic and geological characteristics. In the data collected from 29 research studies in SNNPR, southern Ethiopia, 16 different soil units were distinguished (Annex 1) as the most dominant soil units, viz: (Chromic Luvisols, 37.8% coverage), (Haplic Luvisols, 10.3% coverage), (Andic Lixisol (Humic), 3.4% coverage), (Calcisols Luvisols, 3.4% coverage), (Calcisols (Siltic), 3.4% coverage), (Orthoeutric Nitisol, 3.4% coverage, (Nitic Luvisols, 3.4% coverage), (Mesotrophic vertisols, 3.4% coverage), (Mesotric vertisols, 3.4% coverage), (Luvisosls, 6.8% coverage), (Hypereutric vertisols, 3.4% coverage), (Haplic Calcisols (Humic), 3.4% coverage), (Hapilic Lixisols (Siltic), 3.4% coverage), (Eutric Nitosols, 3.4% coverage), (Chromic Rohdic Luvisols, 3.4% coverage), (Hypereutric vertisol, 3.4% coverage, (Chromic Cambisols, 3.4% coverage), (Orthoeutric Nitisol, 3.4% coverage), (Calcisols Luvisols calcisols (Siltic, 3.4% coverage) which are soil units covering almost the study areas.

According to meta-data analysis, mixed agriculture and agroforesty is the mostly dominant land use type in the study areas which accounts for about 65.5%, intensive cultivation 34.3% (Annex 1), and agro-ecology of the study are mostly under sub-moist tepid which accounts for about 65.4%, moist-cool and sub-humid cold (3.4%), moist tepid to sub-humid-cold (3.4%), moist–cool (10.3%) and sub-moist tepid to moist-cool (17.2%). Geologically, areas were dominated along with rocks, such as Rhyolites, Trachytes which accounts for 61.9%, rhyolites and tracytic tuffs, Volcanic (Basalts and tuffs) 31% and Ignimbrite 6.8%.

pH and EC

It was observed that soil pH varied from 4.48 to 8.24 with a mean 5.9. According to classification of soil reaction suggested by Brady (1985) (Tables 1 and 2, Annex 2), meta analyzed data from different scholars finding (41%) were moderately acidic (5.6 – 6.5), 37.4% were strongly acidic (<5.5), 10.3% were neutral (6.6-7.3) and 10.3% were moderately alkaline (7.9-8.24). The neutral to alkaline pH may be attributed to the reaction of applied fertilizer material with soil colloids, which resulted in the reaction of basic cation on the exchangeable complex of the soil (Singh and Mishra, 2012). The electrical conductivity varied from 0.101 to 0.75 dS/cm, with a mean value of 0.07. On the basis of limits suggested by Muhr et al. (1963) for judging, all data were found in normal range/salt free. Due to high precipitation (1500 mm) and less evaporation demand, the salt accumulation is not prevalent in this region, which is suitable for crop growth.

Nitrogen (N)

Available nitrogen status varied from 0.11 to 2.83% with an average value of 0.28%. On the basis of the ratings suggested by Subbiah and Asija (1956), 13% of the data were found to be very low and 38.3% of the data were found to be low, 34.55 of the data were found to be optimum and high and very high total account for about 13.7%. Low nitrogen status in the soils could be due to low amount of organic carbon in the soil. Since most of the soil nitrogen is found in organic form, low nitrogen has been associated with loss of soil organic matter (Solomon et al., 2002; Gelaw et al., 2014).

Phosphorus (P)

The available phosphorus content varied from 11.2 to 41 ppm with an average of 24.10 ppm on the basis of the limits suggested to Muhr et al. (1963); most of the finding data (27.5%) were low in available phosphorus status and 44.7% of the data were found to be low and the remaining 27.3% were under medium category (Table 2, Annex 2). This indicates that presence of organic matter increases the availability of phosphorus in soil and fixation with Fe and Al. According to Singh and Mishra, 2012 (2012), about 50% of phosphorus is found in organic form and decomposition of organic matter produces humus which forms complex with Al and Fe and protected with P fixation. Similarly, according to Beygi and Jalali (2019), Agegnehu and Sommer (2006), highly weathered soils with pH less than 5.5, results in nutrient deficiencies and toxicities. In such soils, phosphate is unavailable to plant roots because of fixation unless it is applied in large amounts (Abay and Tesfaye, 2011; Elias et al., 1998).

Organic carbon (OC) and Cation Exchange Capacity (CEC)

Values of soil OC are also low to medium, for instance, 54.7% of the data were found to be in medium/optimum range, 34% were found in low range, while the remaining 13.7% were under very low range (Table 2). Organic carbon (OC) varied from 0.26 to 4.1% with an average value of 2.55% (Table 2, Annex 2). Such low values are the consequences of the severe soil erosion, limited inputs, and overgrazing which results in a low vegetation cover (Nyssen et al., 2004; Elias, 2000).

Cation Exchange Capacity (CEC) is almost high which account for about 93.2% and rarely very high (3.4%).

Table 1. Critical levels used for classifying soil fertility parameters analysis result.

Soil parameter	Status	Critical level	Citation
Soil pH (water)	Strongly acidic	<5.5	Ethiosis Team Analysis (2014) and Brady (1985)
	Moderately acidic	5.6-6.5	
	Neutral	6.6-7.3	
	Moderately alkaline	7.3-8.4	
	Strongly alkaline	>8.4	
EC (mS/cm or ds/m)	Salt free	<2	Ethiosis Team Analysis (2014) and Muhr et al. (1963)
	Very slightly saline	2-4	
	Slightly saline	4-8	
	Moderately saline	8-16	
	Strongly saline	>16	
Nitrogen (%)	Very low	<0.15	Ethiosis Team Analysis (2014), Subbiah and Asija (1956)
	Low	0.15-0.3	
	Optimum	0.3-0.55	
	High	0.55-1.05	
	Very High	>1.05	
OC%	Low	<2%	Landon (1984) and Ethiosis Team Analysis (2014)
	Medium	2-10%	
	High	>10%	
Zn (mg/ka or ppm)	Deficient	<0.6	Kirmani et al. (2011), Takkar and Man (1975) and Tahere et al. (2005)
	Marginal	0.6-1.2	
	Sufficient I	1.2-2.4	
	Sufficient II	>2.4	
Cu (mg/ka or ppm)	Deficient	<0.2	Lindsay and Novell (1978) and Kirmani et al. (2011)
	Marginal	0.2- 0.4	
	Sufficient I	0.4-0.8	
	Sufficient II	0.8-1.6	
	Sufficient III	1.6-3.2	
Organic matter (%)	Very low	<0.2	Ethiosis Team Analysis (2014)
	Low	2.0-3.0	
	Optimum	3.0-7.0	
	High	7.0-8.0	
	Very high	>8.0	
Available P (mg/kg)	Very low	0-15	Ethiosis Team Analysis (2014), Muhr et al. (1963).
	Low	15-30	
	Optimum	30-80	
	High	80-150	
	Very high	>150	
Exchangeable K (Cmolc/kg)	Very low	<0.90	Ethiosis Team Analysis (2014)
	Low	0.90-19	
	Optimum	19-60	
	High	60-90	
	Very high	>90	
CEC (me/100 soil g)	Indicate soil infertility	<4	Landon (1984)
	Minimum value	5-15	
	Opt.	15-25	
	High	25-40	
	Very high	>40	
Fe (mg/ka or ppm)	Deficient	<4.5	Lindsay and Novell (1978)
	Marginal	4.5-9	
	Sufficient I	9-18	

Table 1. Contd.

	Sufficient II	18-27	
	Sufficient III	>27	
Mn (mg/kg or ppm)	Deficient	<2.5	Lindsay and Novell (1978)
	Marginal	2.5-3.5	
	Sufficient I	3.5-7	
	Sufficient II	>7	

Table 2. Criteria for assessment of soil chemical characteristics (n=29).

Parameter	Range	Mean	Critical levels				
			Very low %	Low %	Medium %	High%	Very high %
pH (=29)	4.48-8.24	5.9	37.4	41	10.3	10.3	**-**
EC (=29)	0.01-0.75	0.07	100	-	-	-	**-**
Available macronutrients							
N (=29)	0.11-2.83	0.28	13.5	38.3	34.5	10.3	**3.4**
P (=29)	11.2-41	24.10	27.5	44.7	27.3	-	**-**
K (=29)	0.34-2.3	0.93	27.6	72.3	-	-	**-**
OC (=29)	0.26-4.1	2.55	13.7	34	54.7	-	**-**
CEC (=29)	24.8	33.8	-		3.4	93.2	**3.4**

Available micronutrients							
			Marginal	**Sufficient I**	**Sufficient II**	**Sufficient III**	**Deficient**
Fe (=29)	27.1-109.7	72.24	-	10	6.8	83.2	**-**
Zn (=29)	0.71-29.2	14.17	6.8	-	3.4	89.8	**-**
Mn (=29)	32-83.5	64.7	-	6.9	10.2	82.9	**-**
Cu (=29)	0.16-3.44	1.38	-	27.6	44.8	6.9	**20.7**

Sources: Wassie and Shiferaw (2011), Alemu et al. (2016), Abay et al. (2015), Kirmani et al. (2011), Geology Survey Ethiopia (2005), BWFED (2011), CASCAPE (2014) in SNNPR; Wondwosen and Sheleme (2011), EthioSIS (2014) and CSA (2000).

CEC varied from 24.8 to 47.5% with an average value of 33.8% (Table 2, Annex 2). Basically, CEC of soil is determined by the relative amounts and/or type of the two main colloidal substances; humus and clay. Organic matter particularly plays important role in exchange process because it provides more negatively charged surfaces than clay particles do. On the other hand, the decrease in CEC with pH can be attributed to a decline in CEC values as pH-dependent charge (Johnson, 2002).

Zinc (Zn) and Copper (Cu)

Available zinc varied from 0.71 to 29.2 ppm with the mean value of 14.17 (Tables 1 and 2, Annex 2). 89.8% was found in sufficient III range, by considering 1.2 to 2.4 as the critical limits of zinc suggested by Takkar and Man (1975). Analyzed data from the researches collected in Table 3, showed that 6.8 and 3.4% of data were found in marginal and sufficient I range respectively (Table 2, Annex 2). Available copper content ranged from 0.16 to 3.44 ppm with mean value of 1.38 ppm (Table 2). 20.7% were found in deficient range, 44.8% were in sufficient II range, 27.6% of data were found to be sufficient I and 6.9% of data were found to be Sufficient III based on limiting critical levels of Lindsay and Norvell (1978) (Table 1).

Iron (Fe) and Manganese (Mn)

Available Fe content in the soil ranged from 27.1-109.7 ppm with mean value of 72.24 ppm (Table 2). 10% were found in sufficient I, 6.8% were found sufficient II range and the remaining 83.2% of the soils has sufficient III amount of available Fe considering 9-27 ppm as a critical limit suggested by Lindsay and Norvell (1978) (Tables 1 and 2, Annex 2).

Available Mn in the meta data varied from 32-83.5 ppm mean value of 64.7 ppm. Considering <2.5 ppm as a

Table 3. Nutrient inputs under different cropping system in SNNPR, southern Ethiopian small holders' mixed farming.

Crop group	IN1			IN2			IN3			IN4	IN5a		
	N	P	K	N	P	K	N	P	K	N	N	P	K
Cereals	7.1	10.7	0.0	9.0	1.0	8.0	0.7	0.16	0.62	0.1	0.0	0.0	**0.0**
Oil crops	0.3	0.79	0.0	1.0	0.2	6.0	0.7	0.16	0.62	0.3	0.0	0.0	**0.0**
Pulses	0.9	1.1	0.0	3.0	0.3	9.0	0.9	0.16	0.62	3.0	0.0	0.0	**0.0**
Vegetables	0.0	0.01	0.0	22	6.6	26.0	1.0	0.16	0.62	0.6	0.1	0.1	**0.0**
Permanent crops	0.0	0.0	0.0	38	9.8	36.0	1.7	0.16	0.62	1.0	0.1	0.1	**0.1**
Total	8.3	12.6	-	73.0	17.9	85.0	5.0	0.8	3.1	5.0	0.2	0.2	**0.1**

Inflows: IN1: Mineral fertilizer; IN2: organic inputs; IN3: atmospheric deposition; IN4: nitrogen fixation; IN4a: symbiotic N fixation; IN4b: non-symbiotic N fixation; IN5: sedimentation; IN5a: irrigation; IN5b: sediments deposition.
Sources: Haileslassie et al. (2005); Elias (2000); Tilahun et al. (2001); Tsegaye (2001).

critical limit for Mn deficiency (Lindsay and Norvell, 1978), 82.9%, 10.2% and 6.9% were found in sufficient III, II, and I ranges respectively (Table 2). The variations observed in available micronutrient among different soils might be the result of variable intensity of different pedogenic processes taking place during soil development. Decomposition of organic material release micronutrient and also reduces pH locally which assists in mineral solubility. Further availability of metal ions (Zn, Cu, Fe and Mn) increases as the organic matter provides chelating agent for complexation of these micronutrients. This is similar to that of Wondwosen and Sheleme (2011), in their study conducted in southern Ethiopia, and stated that Fe, Mn, Zn, B and Mo were sufficient to support good plant growth.

Based on Meta data analysis, there is wide spatial variation in soil pH, EC and macronutrient status and micronutrients across different landuse in parts of SNNPR, southern Ethiopia. All the variables studied by different scholars showed spatial dependence of the variation at different scales along with landscape. These observed variations enhance different soil fertility management based on their nutrients potential.

Most of the important soil quality indicators such as OC, soil pH, N, available P, exchangeable K, CEC and available micronutrients were influenced by the different landscape positions, particularly at the surface layer. This might be due to a continuous intensive cultivation without appropriate soil management practices which has contributed to the degradation of the important soil quality indicators. Therefore, reducing intensive cultivation and use of appropriate chemical inputs/fertilizers could replenish the degraded soil quality parameters for sustainable productivity.

Nutrient flow and balances in SNNPR, across cropping type

Nutrient input across cropping systems

In SNNPR, southern Ethiopian farmers use specific soil fertility management strategies for different parts of their farms. They grow mainly permanent and vegetables crops near the homestead and others (cereals, pulses and oil crops) on more distant fields. Applications of manure and inorganic fertilizers reflect this differentiation Elias, 2000; Tilahun et al., 2001; Tsegaye, 2001; Abay and Tesfaye, 2011). Currently, DAP and urea is the only inorganic fertilizers applied by smallholders. Potassium application from inorganic fertilizer (IN1) is not reported in Ethiopia (N) application. Fertilizer trials conducted on major cereal crops (for N, P and K) also indicated that cereal crops were not responsive to K (FAO, 1991). However, the importance of long term K fertilization must not be overlooked, as leaching, erosion and depletion via crop harvest may deplete K stocks.

The input to permanent crops, vegetables, pulses and oil crops from IN1 is virtually absent, while cereals obtain about 7.1 kg N/ha/yr and 10.7 kg P/ha/yr (Table 3). Among cereals, teff (*Eragrostis tef* (Zucc) and wheat (*Triticum durum* and *Triticum aestivum* L.) receive more than 60% of inorganic fertilizer applied by smallholders in Ethiopia. Preference for teff and wheat production is partly related to profitability. Fertilizer use on those crops is more profitable than sorghum (*Sorghum bicolor*) or maize (*Zea mays*) which is mainly grown in areas with a high risk of drought. Stable and higher prices for teff and wheat may also encourage smallholders to use fertilizer (Demeke et al., 1998).

Permanent crops receive a high amount of nutrient inputs from organic fertilizer (IN2), which was estimated at 38 kg N/ha/yr, 9.8 kg P/ha/yr and 36 kg K/ha/yr. Enset or false banana (*Ensete ventricosum* L.) in the Southern Nation Nationalities Peoples Region (SNNPR) received the highest amount of IN2 per unit area. This was comparable with the results of (Tsegaye, 2001; Elias et al., 1998; Haileslassie et al., 2005) who reported that coffee (*Coffea arabica*) and false banana were major IN2 receivers in the Sidama zone of SNNPR. Application of IN2 to vegetables like potato (*Solanum tuberosum* L.) was also high (Table 3).

The proportion of N from N-fixation in crops ranges

Table 4. Nutrient outputs under different cropping systems in SNNPR, southern Ethiopian smallholders' mixed farming system.

Crop group	OUT1[a]			OUT2			OUT3		OUT4	OUT5-USLE[b]		
	N	P	K	N	P	K	N	K	N	N	P	K
Cereals	2.3	1.8	1.1	2.3	0.9	4.0	5.1	3.204	1.6	25.8	4.9	17.9
Oil crops	0.8	0.1	0.9	0.2	0.3	0.9	1.0	3.0	0.9	14.2	3.9	13.0
Pulses	5.1	1.1	3.0	2.3	0.2	5.7	2.6	3.204	0.5	15.7	3.0	11.7
Vegetables	7.7	1.0	5.2	8.3	1.0	10.7	10.9	3.204	2.5	10.5	0.5	4.8
Permanent	4.5	0.9	3.3	12.4	1.2	30.6	12.1.	3.204	6.3	3.10	0.7	1.2
Total	20.4	4.9	13.5	25.5	3.6	51.9	31.7	16.0	11.9	64.3	13.0	48.2

Out flows: OUT1: Harvested products; OUT2: residues removed; OUT3: leaching losses; OUT4: gaseous losses; OUT5: erosion.
Sources: Smaling et al. (1996), De Jager et al. (1998), Haileslassie et al. (2005), Elias (2000), Tilahun et al. (2001), Tsegaye (2001).

from zero, usually where environmental stresses is high and prevent nodulation, to 98% in crops growing in ideal conditions. Amounts of N fixed up to 450 kg/ha have been recorded in the tropics (Smithson and Giller, 2002).

In addition to soil fertility, intensity of crop cultivation, cropping pattern, livestock management system (open grazing, confined management) and differences in other competitive uses of manure (e.g. household energy) were the major cause of variation in the application of IN2 across the different states (Table 3). SNNPR regional states had remarkably higher amount of IN2 compared to the other regions. This can be accounted for by the large area of Enset crop (staple food in major parts of the region) that requires regular application of manure (Haileslassie et al., 2005; Elias, 2000; Tilahun et al., 2001; Tsegaye, 2001).

Nutrient outputs across cropping systems

The review here reveals that losses of soil nutrients occur in different cropping systems. For instance, OUT1 from pulses vegetable and permanent crops was somewhat higher (Table 4). Haileslassie et al. (2005) study showed that there were comparable trends for output via crop residues (OUT2). Permanent crops and vegetables had highest OUT2 compared to cereals and oil crops.

The magnitude of leaching depends mainly on climate, soil type and the quantity of dissolved or soluble nutrients present in the soil. As indicated in Table 4, permanent crops had the highest estimates of N leaching accounting for high amount of fertilizer (mainly IN2) under this system. However, in contrast to the annuals, permanent crops can extend their root systems deeper and capture materials moving beyond the plow layer. Some studies consider layer thickness or rooting depth to calculate such effects (e.g. FAO, 2001). Similar to leaching losses, denitrification was also higher under permanent and vegetable crops (Table 4). Based on the facts done by Haileslassie et al. (2005), nutrient losses via erosion in cereals, oil crops and pulses were high. Vegetable and permanent crops had the lowest value (Table 4). The difference across cropping system was mainly caused by the values of land cover factor (C).

Notably, in SNNPR with a high IN1 level, there was also observed a high OUT1. At regional level, the losses of N, P and K via harvested crops (OUT1) were estimated at 20.4, 4.9 and 13.5 kg/ha/yr respectively (Table 4). In SNNPR, southern Ethiopia intensive cultivation is as compared to other regions (Haileslassie et al., 2005; Elias, 2000; Tilahun et al., 2001; Tsegaye, 2001; Amede and Taboge, 2007). Nitrogen leaching is higher in SNNPR, because of higher IN1 and IN2. In Table 4, denitrification (OUT4) may be the least important cause of N loss with a magnitude of 11.9 kg/ha/yr, a value which is close to the result of Van den Bosch et al. (1998), Haileslassie et al. (2005) and Elias (2000).

Nutrient balances as indicators of soil fertility decline

Current debate is on whether nutrient balances can be useful sustainability indicators. The balance as such may not provide all the information (Shepherd and Soule, 1998). Nutrient stocks are also quite important, and are subject to continuous change as a result of natural and man-induced processes. Hence, a rich soil having high depletion differs markedly from a poor soil with low depletion. Smaling et al. (1996) developed the following simple classification to partition production systems on the basis of nutrient balances and stocks:

- Sum of inputs > sum of outputs
- Sum of inputs = sum of outputs
- Sum of inputs < sum of outputs, and:
- With high nutrient stocks and availability (soil fertility decline may not be noticed)
- With unbalanced nutrient stocks and availability (unfavorable (N/P/K ratios).
- With low nutrient stocks and availability (soil fertility decline is noticed).

As of now, many regions in Ethiopia agro ecosystems are in Class III a, b and c. Soil nutrient stocks in all regional

Table 5. Nutrient balance under different cropping systems in SNNPR, southern Ethiopian smallholders' mixed farming system.

Crop group	IN1+IN2+IN3+IN4+IN5-USLE			OUT1+OUT2+OUT3+OUT4+OUT5-USLE			Balances (USLE)		
	N	P	K	N	P	K	N	P	K
Cereals	37.1	14.2	8.62	43.5	7.6	26.204	-6.4	-12	-17.584
Oil crops	15.7	1.15	6.62	17.1	4.3	17.8	-1.4	-3.15	-11.18
Pulses	26.2	1.56	9.62	37.5	4.3	23.604	-11.3	-2.74	-13.984
Vegetables	100.1	6.87	26.62	49.5	2.5	23.904	50.6	4.37	2.716
Permanent crops	120.2	10.06	38.72	56.3	2.8	36.304	63.9	7.26	2.42

Sources: CASCAPE (2014), Amare et al. (2005), Haileslassie et al. (2005) and Elias et al. (1998).

states were decreasing with the exception of areas under permanent and vegetable crops (Smaling et al., 1996).

Full nutrient balances

Full nutrient balances is not like that of the partial balance, which is often applied in agricultural assessments at various scales, all major input and output fluxes are considered in a full balance. Large differences occurred between crops grown on field plots and crops grown on homestead plots. Permanent and vegetable crops had positive balances while all other cropping systems had strong negative full balances. Erosion was one of the major outflows that affect the positive partial balances mentioned in this study. As permanent crops can cover the soil and intercept falling raindrops close to the surface, this cropping system is less susceptible to erosion losses. Hence, permanent crops had positive full balance, although less positive compared to the partial balance. Similar trends of nutrient depletion in field and homestead plots have been reported for the Southern Ethiopian Highlands (Tilahun et al., 2001; Elias et al., 1998).

In Southern Nation Nationalities Peoples Regional State (SNNPR), a higher rate of fertilizer or dung input have a positive partial balance even though harvests were also higher. The level of inputs (IN1 and IN2) was clearly higher than the outputs (OUT1 and OUT2), resulting in a positive partial balance for all nutrients (Table 5). Higher inorganic and organic sources of nutrient inputs and relatively strong positive partial nutrient balances in intensively cultivated regions, reflect the level of agricultural development, market proximity and higher prices for the agricultural products (CSA, 2000; Sheldrick et al., 2003). P depletion rates generally were not as high as N and K rates. This can be explained by the low quantity of P in plant and soil systems and because it is not susceptible to leaching. Similar trends of P depletion were reported by Sheldrick et al. (2003). N and K balances in SNNPR were negative, but P is positive (Table 6). The regional level depletion rate for N, P and K was calculated at -31 kg/ha/yr + 71 kg/ha/yr and -169 kg/ha/yr by (USLE) respectively (Table 6) (CSA, 2000; Haileslassie et al., 2005; Tilahun et al., 2001; Elias et al., 1998; Tsegaye, 2001; Amede and Taboge, 2007; CASCAPE, 2014 Amare et al., 2005.

Solutions towards combating soil fertility decline

Soil nutrient depletion is illustrated by small increases in crop productivity, even in years with adequate rainfall. As a result, more intensive land use (e.g. by fertilizer application) has become necessary to reverse the trend of declining per capita food production. Agriculture in Ethiopia is no exception; more soil nutrients are exported compared to natural and anthropogenic inputs (Okumu, 2000). Stoorvogel and Smaling (1990) predicted for Ethiopia that the national nutrient balances would be on average: -47 kg N/ha, -15 kg P_2O_5/ha and -38 kg K_2O/ha for the year 2000. This prediction was twice as high as the average value for sub Saharan Africa and indicates the severity of nutrient depletion in Ethiopia.

Nutrient depletion in Ethiopia especially in SNNPR has several causes. Application of organic fertilizer like crop residues and manure is limited around home stead than outfield. In addition, because of competitive uses (e.g. animal feed and household energy). Also, problems in the fertilizer sector have restricted the wider use of inorganic fertilizers, consequences of cost of minerals fertilizers, limited soil water conservation and low grain prices on the market probably discouraged farmers from using fertilizer (Demeke et al., 1998).

As reported by Haileslassie et al. (2005), Tilahun et al. (2001), Elias et al. (1998), Tsegaye (2001), Amede and Taboge (2007), CASCAPE (2014) and Amare et al. (2005), the regional scale reveals large differences in nutrient balances, both with respect to size and the major nutrient fluxes involved. In regions with intensive agricultural management like SNNRP, the full balance was strongly negative, compared to the less intensively cultivated regions (e.g. Afar, Somali). Thus, it is imperative to formulate cropping system and region-specific nutrient management policies and strategies.

The negative nutrient balances do not necessarily mean that crop production declines, as soils may still have sufficient stocks of nutrients to keep productivity up

Table 6. Full nutrient balances in SNNPR, southern Ethiopia (kg/ha/yr).

Location	Farming system	IN1+IN2+IN3+IN4+IN5-USLE			OUT1+OUT2+OUT3+OUT4+OUT5-USLE			Balances(USLE)			Citation
		N	P	K	N	P	K	N	P	K	
At regional level (SNNPR)	Cereals, Oil crops, Pulses, Vegetables and Permanent crops	91.5	31.4	37.6	153.8	21.5	130	-62	+9	-41	CASCAPE (2014), and Haileslassie et al. (2005)
Bule	Wheat, Barley, Bean, Enset, Potato and Sorghum and Teff	1.5	30.5	29.5	5.5	18.5	29.5	-4	+12	0	CASCAPE (2014)
Cheha	Wheat, Barley, Bean, Enset, Potato and Sorghum and Teff	20.4	26.5	21.6	35.6	27.5	59.6	-38	+1	-38	CASCAPE (2014) and Haileslassie et al. (2005)
Enamore	Wheat, Barley, Bean, Enset, Potato and Sorghum and Teff	19.8	24.6	26.8	38.8	33.6	61.8	-19	+9	-35	CASCAPE (2014)
Melga	Wheat, Barley, Bean, Enset, Potato and Sorghum and Teff	55.2	35	31	56.2	48	45	-1	+13	-14	CASCAPE (2014)
Mesrk Azernet	Wheat, Barley, Bean, Enset, Potato and Sorghum and Teff	14	17	24.1	36	29	42.1	-22	+12	-18	CASCAPE (2014) and Elias et al. (1998)
Wolaita	Enset-coffee based mixed farming	52	36	32	49	41	39	+3	+5	-7	CASCAPE (2014)
Gurghe highlands	Enset based farming system	130	75	45	62	82	68	+68	+7	-23	CASCAPE (2014)

Sources: Haileslassie et al. (2005), Tilahun et al. (2001), Elias et al. (1998), Tsegaye (2001), Amede and Taboge (2007), CASCAPE (2014).

for many years (at least in some areas). Connecting nutrient flows to stocks and examining temporal variability for more than one production year, will lead to more reliable conclusions on the sustainability of Ethiopian smallholders farming systems (Haileslassie et al., 2005; Amede and Taboge, 2007; CASCAPE, 2014).

Mineral fertilizer recommendation SNNPR, southern Ethiopia

Enhancing agricultural productivity is one of the central challenges to achieving food security and poverty reduction in SNNPR, southern Ethiopia. Considering the fact that soil fertility is one of the biggest challenges, an obvious strategy is to increase fertilizer application and promote good agronomic practices to enhance productivity (Asgelil et al., 2007; Ayalew et al., 2010). So, in order to increase agricultural yields, the government of Ethiopia has launched an extension package which gives more attention to high external inputs and high yielding varieties (Yohannes, 1999; Elias, 2002; ATA, 2013; Dobermann and Cassman, 2002). The introduction of mineral fertilizers to Ethiopia started in the 1970s by the Ministry of Agriculture through Wolaita Agricultural Development Unit (Elias, 2002). The national blanket recommended application rate for Ethiopia is 100 kg of diammonium-phosphate (DAP) and 50 kg Urea per hectare (Elias, 2002; Nandwa and Bekunda, 1998). However, fertilizer recommendation for cropping patter in AEZs must be based on basic data of soil, climate and crops as pre-requisite for fertilizer recommendation which can ensure efficient and economic use of chemical fertilizers and organic manures. Soil related data include pH, texture, organic matter and some other soil properties. Nutrient requirements for a crop also depend on overall environmental conditions and yield potential. For AEZ-based fertilizer recommendation, key attention has been paid to the information of cropping patterns and land type along with soil pH, SOM and nutrient contents (Dobermann and Cassman, 2002; ATA, 2013; FAO, 1991, 2001).

Even fertilizer application in Ethiopia including SNNPR, southern Ethiopia blanket recommendation, the real experience is showing that farmers are applying only smaller amounts of mineral fertilizer between 7 and 10 kg/ha annually (MoARD, 2007; Elias, 2002; Croppenstedt et al., 2003; FAO, 2001; Yirga and Hassan, 2013). By 1995, only two-third of the rural households in Ethiopia has been using mineral fertilizer at this lower rate (Pender et al., 1999). Most of the mineral fertilizer is used in irrigated fields (Shewangizawn et al., 2021). However, many farmers are reluctant to use chemical fertilizer. This is due to the limited capacity of the farmers to purchase and fear of debt (Elias, 2000), unreliable rainfall (World Bank 2007) and the ever increasing cost of mineral fertilizer (Elias 2000). The sharp drop in the prices of harvested products is also another reason (Müller-Sämann and Kotschi, 1994).

Crop response to fertilizer application in SNNPR, southern Ethiopia

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 (Wakene and Hiluf, 2006). For long, National Fertilizer Input Unit (NFIU) recommended 100 kg urea per hectare (46% N) and 100 kg DAP per hectare (18% N and 46% P_2O_5) as blanket fertilizer recommendation in the country was applied despite many criticisms. Major crops (maize, teff, wheat, barley, sorghum and crop types in Table 7 showed that grain yield responses to nutrient applications have been agronomical and economically satisfactory in SNNPR, Ethiopia. Yet, some of the inorganic fertilizer rates, timing and way of application that had been taking place in different parts of the country are not site and crop specific. For instance, the findings suggested that blanket recommendation at national level is not appropriate so that site specific recommendations would be more beneficial (Tanner et al., 1999; Dobermann and Cassman, 2002; ATA, 2013; FAO, 1991, 2001) (Table 7).

As different scholars reported in Table 7, a number of researches which were conducted in SNNPR, southern Ethiopia in different years showed that nitrogen, phosphorus and potassium fertilizers are very responsible across different crops and revealed an increased grain yields which were economically and agronomically positive in the study areas (Table 7). For instance, application of K alone or in combination with NP on maize was also found to be economically feasible. However, the research which was implemented on teff crop by Kelsa (1998) has not showed responses to both nitrogen and phosphorus fertilizers' application in Awassa (Votric Andosols). This indicates that the soil is not deficient in N and P. An experiment conducted on NP requirement of sunflower also indicated that the soil was not deficient in these nutrients (Damene, 2003). This shows the core constraints of SNNPR, southern Ethiopia soils which include depletion of soil organic matter (SOM) due to widespread use of biomass as fuel, depletion of macro and micronutrients, removal of top soil by erosion, change of soil physical properties, and increased soil acidity with time (IFPRI, 2010; Taye, 2007). On top of these, the usage of fertilizers in the country is not based on soil test results and below the recommended level; farmers do not fully implement the recommended soil management practices. These have resulted in a steady decline of nutrient levels in the soil (Diriba- Shiferaw et al., 2013; Wakene and Hiluf, 2006; Admassu et al., 2016).

Based on facts obtained in Table 7, nutrient application of plants could be different from site to site depending on different factors soil nutrient status and the like. For sustainable production of plant/crops for a specific area, specific fertilizer reference is very decisive owing to the production of any crops/plants yield that could be influenced by nutrients status of the soil in addition to genetic factors.

Fertilizer trends in SNNPR, southern Ethiopia from 2003-2011

Farmers use diammonium phosphate (DAP) and urea as sources of fertilizers. Mean application rate of DAP and urea varied among farmers' soil types. The use of inorganic fertilizer was higher on less fertile soil types than on fertile soils (MoRD, 2012; Wakene and Hiluf, 2006; FAO, 1991, 2001; ATA, 2013).

Ethiopian agriculture is dominated by smallholder farmers (< 25 ha) with over 90% of cultivated land under food crops (mostly grains). As available arable land is becoming increasingly scarce, increases in production will be driven largely by intensification of inputs rather than expansion of land area. This makes fertilizer consumption a key element of any agricultural strategic plan as appropriately emphasized in the GTP (ATA, 2013; CASCAPE, 2014).

Fertilizer sales/consumption have increased by more than 100% between 2002 and 2011, with an average rate of 6% per year, more so for urea than for DAP. Consumption levels vary across the year in SNNPR, southern Ethiopia using an average of 92% of total fertilizer sales between 2003 and 2011 which is increasing from year to year. But the problem is that blanket recommendation is still in function at national level is which is not appropriate and site specific recommendations based on the soil test results would be more beneficial (Tanner et al., 1999). Therefore, to come up with solution, site-soil-crop specific fertilizer recommendation with appropriate rate must be further studied to obtain high yield and reduce waste of inputs that exist as trends before (MoARD, 2011; ATA, 2013; CASCAPE, 2014). Due to this, uses of balanced fertilization are recommended to combat soil fertility problems and exploring the potential crop productivity.

CONCLUSION AND RECOMMENDATION

Soil nutrient depletion is becoming one of the major challenges of agricultural production for the stallholder farmers in SNNPR, southern Ethiopia. Even though there is a high loss of soil nutrient in Ethiopia through soil erosion, continuous uptake by plants and intensive cultivation with less soil fertility management, there is limited information about status of soil fertility across the geographic landscapes. According to this review, the soil fertility status for nitrogen, phosphorus and potassium soil

Table 7. Crop response to fertilizer application in SNNPR, southern Ethiopia.

Location	Soil type	Crop type	AEZ	Rate of fertilizer	Yield effect	Citation
Chencha (Gindogambla and Dokotsida), southern Ethiopia 9° 5'N and 39°.45'E	loam Haplic Alisols	Wheat	Sub-moist Tepid to moist cool	N (0, 23, 46 69 and 92 kg/ha)	More yield was obtained at rate of 69 kg/ha (165.4% over control without treatment as compared to other rates.	Bekalu and Mamo (2016)
Hagerselam (38°27'44'' and 06°26'59'') and Chencha (38°4' E and 5°55' N), southern Ethiopia	Luvisols and loam Haplic Alisols	Barley	Moist cool	N-P-K fertilizers at the rate of 46-40-50 kg/ha	The highest barley grain yield were recorded from NPK and 1/2 recommended lime rate at both sites	Shiferaw and Anteneh (2014)
Wolaita (Boloso sore and Damot sore) southern Ethiopia.7°04.196'N and 37°4330'E, 6°56''N and 37°.39'E respectively	Nitosols	Haricot Bean (Hawassa Dume and Omo-95 varieties)	Sub-moist Tepid	P (0, 10, 20 and 30 kg/ha)	More yield were obtained at rate of 30 kg/ha (152 and 155% over control without treatment respectively).	Mesfin et al. (2014)
Hadero, Southern Ethiopia. 07° 11´52" - 07° 11' 89" N and 37º39'49" - 37° 39' 58"E.	Luvisosls and Nitosols	Maize	Sub-moist Tepid to moist cool	NPK (0:0:0; 0:0:60; 92:20:0 and 92:20:60)	Increased grain yield was obtained from NPK by 41% over that produced by NP treatment	Admasu et al. (2015)
Doyogena, southern Ethiopia	Luvisosls, Nitosols and Cambiosls	Wheat	Sub-moist Tepid to moist cool	N (0, 23, 46 and 69)	Increased grain yield was obtained at rate of both 46 and 69 kg/ha by 202% over control without treatments	Wogene and Agena (2017)
Dilla, southern Ethiopia 6° 18' 11"N and 38° 17' 40"	Chromic Luvisols	Teff (Kuncho) variety	Semi-arid to warm	NP (46 and 46 kg/ha) applied in broadcasting	Application of the recommended rate of nitrogen half dose at sowing and ½ dose at tillering increased the growth and yield	Shiferaw and Tewodros (2016)
Derashe, southern Ethiopia	Nitosols and Cambiosls	Sorghum	Moist-cool	N (0, 10, 23, 46, 69,92 and P (0, 10, 20, 30 kg/ha)	Increased sorghum grain yield by 379.5% over control without treatment was at rate of N/P (92/30 kg/ha)	Nebyou and Muluneh (2016)
Hosana, southern Ethiopia	Nitisols	Wheat	Moist-cool	69/20 kg ha^{-1} N/P	Highest grain yield at 23/20 kg ha^{-1} N/P Recommended N/P rate	Areka Agricultural Research Center (2000)
Kokate, southern Ethiopia 6° 52' 42" N and 37° 48' 25.2" E	Nitosol	Barley and wheat	Sub-moist tepid	41/20 kg ha^{-1} NP	Highest yield obtained	Areka Agricultural Research Center (2000)
Bobicho research site (Hossana), southern Ethiopia 7° 34' 14.6''N and 37° 50' 06.1''E.	Profondic Luvisols	Teff (Ajora-1') variety	Sub-moist tepid	Urea and (TSP) N (0, 23, 46 and 69 kg/ha; whereas P was applied at 0, 10, 20, 30 and 40	Maximum yield was obtained at the rate of 23/30 kg/ha N/P	Abay et al. (2011
Areka, southern Ethiopia (7° 3' 26'' N and 37° 40' 52''E.	Haplic Alisols	Teff (DZ- 01- 354, DZ-01-196)	Sub-moist tepid	Urea (DAP) N (0, 23, 46 and 69 kg/ha, P (0, 10, 20, 30 and 40 kg/ha).	No response to N application for teff production. But, grain yield increased due to application of P (50 to 100 kg/ha).	Abay et al. (2011
Awassa, southern Ethiopia (07° 03' 19.1''N and 38° 31' 08''E.	Vitric Andosols,	Teff (Dhabi) variety		Urea and (DAP), N (0, 23, 46 and 69 kg/ha, P (0, 10, 20, 30 and 40 kg/ha).	No response for both DAP and Urea	Kelsa (1998) and Abay et al. (2011)
Angacha, southern Ethiopia. 7° 0' N and 38° 29' E	Alfisol, Luvisols	Potato	Sub-moist tepid	N/P (0/0, 36.7/13, 55/19.6, and 73.4/26 kg/ha) national recommended rate 111 kg N and 39 kg /ha P	Increased yield (34 t/ha) was obtained by increasing both N and P (111 and 39 kg /ha respectively)	Abay and Tesfaye (2011)

Table 7. Contd.

Kokate, Southern Ethiopia. 6° 52' 42" N and 37° 48' 25.2" E	Nitosol	Potato	Sub-moist tepid	N/P (0/0, 36.7/13, 55/19.6, and 73.4/26 kg/ha) national recommended rate 111 kg N and 39 kg /ha P	Increased yield (34 t /ha) was obtained by increasing both N and P (111 and 39 kg /ha respectively)	Abay and Tesfaye (2011)
Malga Woreda, southern Ethiopia. 7.1–7.017° N and 38.35 - 38.5833° E		malt barely cultivars	Semi-arid-warm to moist-cool	A blanket application of DAP and 46% N	Increased grain yield from the rate of N (98.5 kg N/ha).	Biruk and Demelash (2016)
Hadiya, Kambata, Wolaiyta and Dawro zones	Nitosols	wheat	Sub-moist-tepid to Moist cool	11°N and 46 P_2O_5	Economical increased yield obtained in the areas, since both fertilizers are shown responses.	Woldeyesus Sinebo et al. (2012)
Gozo-Bamush Dawuro, Southern Ethiopia	Haplic Alisols	Wheat	Sub-moist tepid	69°N and 69 P_2O_5	Economical increased yield obtained in the areas, since both fertilizers are shown responses.	Damene (2003)

are at levels from very low to low, but micronutrient ranges shows that they are in sufficient ranges. This showed that SNNPR, southern Ethiopia soil acidity is a major constraint in agricultural production; hence availability and solubility of micronutrients became high in the area.

The balance of nutrient was also determined by monitoring N, P and K flowing to the soil with mineral fertilizer. Accordingly, N and K balances in SNNPR, southern Ethiopia were negative, but P is positive. The regional level depletion rate for N, P and K was calculated at -62 kg/ha/yr, +9 kg/ha/yr and -41 kg/ha/yr by (USLE) respectively. Nutrient balance of phosphorus become positive because P is less susceptible to leaching since its fixation is high in the soil.

A change in land use systems and cropping types cause reduction in soil organic matter and other soil nutrients responsible for soil fertility and productivity and lead to soil degradation. Soil fertility and productivity of any land area depends on the SOM and nutrient content of soil and also on the land use and management practices. Thus, to understand the sustainable use potential of the land and associated effects, it is necessary to know the effect of land use on soil properties associated with soil fertility and productivity.

Mineral fertilizer consumption is currently increasing mainly for major crops, but the rate of application is still blanket fertilizer recommendation which deals with N, P and K doses only. Farmers' use their own blanket fertilizer recommendation based on their capacity to afford it. As mentioned in the main body of the review, almost reviewed crop types showed responses to fertilizer application and increased grain yield were also obtained in different parts of the region. This indicates that soil in SNNPR, Ethiopia is in deficient level. Therefore, inputs are needed to replace the lost nutrient from the soil. Having limited information on soil fertility status in different location in the country is a great problem in soil fertility management. In fact, the EthioSIS-ATA in collaboration with stakeholders, is currently pursuing a rapid development program on assessment of the soil resources of the country to establish a national soil resources database, and assess the nutrient status of agricultural land to produce soil fertility maps of a number of districts in the country and come up with recommendations for fertilizer applications and other management interventions. However, without detailed soil related information at specific local level, sustainable crop production could not be achieved. Hence, prior to recommending any soil management options, soil nutrient supply potential has to be assessed. Thus, more research needs to be carried out at a granular, actionable level and sustainable land use management options have to be set and applied. Despite these facts, the spatial fertility status of soils models should be necessary.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ANNEXES,

Table 1. Physicochemical properties and Nutrient Status of soil characteristics in different part of southern Ethiopia.

Location	Soil type	Geology	AEZ	Land use type	pH-H_2O	EC ms/cm)	Exch.K (me/100g)	N%	OC%	Ava.P (ppm)	CEC(meq/ 100 g soil)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm
Huletegna Choroko, Southern Ethiopia, 07° 20' 34.5" N and 38° 06' 30.0" E	Andic Lixisol(Humic)	Ignimbrite	Sub-moist-tepid	Intensive land use.	8.24	0.08	0.7	0.26	0.5	13.53	37.5	0.71	69.1	63.4	0.16
Kontela, Southern Ethiopia, 07° 58' 09.7 "N and 38° 43' 09.9" E	Calcisols Luvisols calcisols(Siltic)	Rhyolitic volcanic	Sub-moist tepid	Mixed agriculture	7.94	0.58	0.98	0.45	3.5	13.29	36.4	15	27	35.6	0.41
Yerim, Southern Ethiopia, N 07° 42" 04' and E 37° 58" 06'	Chomic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs	Sub-moist tepid	Mixed cropping, intensive land use.	5.8	0.05	0.56	0.21	1.64	26.9	32.6	6.06	60.77	64.41	0.98
Adazer Abicho, Southern Ethiopia, N 07° 53" 42' and E 38° 05" 31'	Chomic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs	Moist - cool	Mixed cropping, intensive land use	4.85	0.06	0.61	0.22	2.09	25	31.5	16.9	95.3	74.4	1.8
Kocho, Southern Ethiopia, N 06° 55" 54' and E 38° 33" 01'	Chomic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs.	Sub-moist-tepid	Mixed cropping, intensive land use	6.38	0.13	1.65	0.19	1.79	33.7	33.6	24.9	70.6	69.8	1.39
Adazer Sebel,Southern Ethiopia, N 07° 52" 33' and E 38° 03" 49'	Chomic Luvisols,Haplic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs	Moist - cool	Mixed cropping, intensive land use	5.1	0.045	1.2	0.22	2.1	25.1	34.5	9.6	102	75.6	1.9
Sintaro, Southern Ethiopia, N 06° 56" 07' and E 38° 32" 42'	Chromic Cambisols, Orthoeutric Nitisol	Rhyolites, Trachytes, rhyolites and tracytic tuffs.	Sub-moist-tepid	Mixed cropping, intensive land use	5.3	0.05	0.56	0.19	2.2	31.7	36.8	15.4	76.9	55.6	0.78
Moche, Southern Ethiopia, N 08° 02" 59' and E 38° 00" 50'	Chromic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs	Sub-moist tepid	Mixed agriculture Enset and maize	4.48	0.04	0.47	0.28	3.8	15.7	32.8	4.2	76.6	83.47	2.15
Yeferzeye, Southern Ethiopia, N 08° 08" 41' and E 37° 55" 41'	Chromic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs	Sub-moist tepid	Mixed agriculture	5.2	0.12	0.56	0.19	1.71	22.8	36.9	4.47	63.07	78.76	0.65
Kunber, Southern Ethiopia, N 07° 57" 55' and E 37° 52" 53'	Chromic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic	Sub-moist tepid	Mixed cropping, Teff is dominant	5.6	0.03	0.82	0.34	3.85	41	30.7	16.3	74.76	32	1.1

Table 1. Contd.

Agata, Southern Ethiopia	Chromic Luvisols	Volcanic(Basalts and tuffs)	Sub-moist tepid and moist-cool	Mixed Agriculture	5.94	0.01	0.36	0.28	3.42	33	29.5	1.96	71.89	43.12	1.48
Gomosha, Southern Ethiopia	Chromic Luvisols	Volcanic(Basalts and tuffs)	Sub-moist tepid and moist-cool	Mixed Agriculture	5	0.05	0.45	0.22	2.4	22.7	34.3	14	103.1	80.1	3.2
Basura, Southern Ethiopia	Chromic Luvisols	Volcanic (Basaltts and tuffs)	Sub-moist tepid and moist-cool	Agro -forestry	5.5	0.5	0.35	0.45	3	37.9	34.3	23.1	109.7	79.3	3.44
Illalcha, Southern Ethiopia	Chromic Luvisols	Volcanic (Basaltts and tuffs)	Sub-moist tepid and moist-cool	Intensive land use	4.8	0.16	0.42	0.4	4.1	21.5	36.43	9.5	78.5	77.8	1.71
Wordenen, Southern Ethiopia, N 08° 09” 37’ and E 37° 46”33’	Chromic Rohdic Luvisols, Hypereutric vertisol	Magdala group, Rhyolites, Trachytes, rhyolites and tracytic tuffs	Sub-moist tepid	Mixed agriculture	6.51	0.1	2.01	0.31	3.7	23.8	29.6	23.61	75.64	79.83	2.01
Kindo Koye,Southern Ethiopia, 6° 52.82’ E and 37° 52.42’	Eutric Nitosols	Volcanic(Basalts and tuffs)	Sub-moist tepid	Mixed agriculture	6.05	0.12	2.09	0.16	1.9	14.6	24.8	12.4	65.3	61	0.19
Taba, Southern Ethiopia, 07° 00’ 49.9” N and 037° 53’ 57.6” E	Hapilic Lixisols (Siltic).	ignimbrite	Sub-moist tepid	Intensive land use.	6.5	0.07	0.9	0.35	3.9	11.2	31.5	10.7	46	62.3	0.17
Tenkaka Umbolu, Southern Ethiopia, 07° 01’ 19.9” N and 38° 20’ 23.6” E	Haplic Calcisols (Humic).	Rhyolitic volcanic	Sub-moist tepid	Intensive land use.	6.7	0.3	1.9	0.41	4.1	12.98	37.5	12.04	28	54	0.28
Guguma, Southern Ethiopia, N 06° 59” 21’ and E 38° 42” 32’	Haplic Luvisols	Rhyolites, Trachytes, rhyolites and tracytic tuffs	Sub-moist Tepid	Mixed cropping, intensive land use	5.7	0.09	1.4	0.23	3.1	39.3	29.5	23.4	85.2	54.6	1.5
Jole Andegna, Southern Ethiopia, 08° 12’ 25.9 N and 38° 27’ 33.2” E	Haplic Luvisols	Volcanic(Basalts and tuffs)	Sub-moist tepid	Mixed agriculture	7.61	0.11	0.5	2.86	0.36	13.69	33.6	9.1	79.1	61.3	0.9
Angacha, Southern Ethiopia, 7° 03’ N and 38° 29’ E	Haplic Luvisols	Volcanic(Basalts and tuffs)	Sub-moist-tepid	Mixed cropping, Teff is dominant	6	0.09	0.84	1.6	0.26	21.5	34.5	12.3	72.4	36	1.6
Ewan, Southern Ethiopia, N 08° 13” 43’ and E 37° 48”45’	Hypereutric Vertisols	Magdala group, Rhyolites, Trachytes, rhyolites and tracytic tuffs	Sub-moist tepid	Intensive land use.	6.28	0.14	0.56	0.11	1.07	32.1	47.5	4.01	49.72	63.52	1.92

Table 1. Contd.

Kembata Tambaro 4 Woreda Southern Ethiopia) 7.12˚ to 7.42˚N and 37.44˚ to 38˚E	Luvisosls,Nitosols and Cambiosols	Rhyolites, Trachytes, rhyolites and tracytic	Moist tepid and Sub-humid-cold	Mixed agriculture	6.55	0.13	2.3	0.51	3.6	26.7	32.4	21.3	73	71.5	1.03
Hagere Selam, Southern Ethiopia, 6° 9' N and 35° 3' E	Luvisosols	Rhyolites, Trachytes, rhyolites and tracytic tuffs.	Moist - cool	Mixed agriculture	4.7	0.12	1.9	0.31	2.7	11.2	34.6	22.3	71.3	70.6	2.3
Kereda, Southern Ethiopia, N 08° 02" 56' and E 37° 45" 49	Mesotric vertisols	Rhyolites, Trachytes, and Tuffs.	Sub-moist tepid and moist-cool	Mixed cropping, Teff is dominant	6.02	0.1	0.94	0.25	2.1	24.4	32.9	26.54	84.66	68.09	1.83
Emejar, Southern Ethiopia, N 07° 43" 20' and E 38° 00" 06'	Mesotrophic Vertisols	Magdala group, Rhyolites, Trachytes, rhyolites and tracytic tuffs.	Sub-moist tepid	Mixed cropping, intensive land use.	5.42	0.07	0.34	0.21	2.56	28.2	32.9	9.07	72.24	73.4	2.34
Dero, Southern Ethiopia (SE)	Nitic Luvisols	Volcanic (Basaltts and tuffs)	Sub-moist tepid	Agro -forestry	5.6	0.75	0.91	0.45	2.6	34.8	32.5	16.1	55.6	69.2	1.8
Chencha ,Southern Ethiopia, 6° 13' N and 37° 6' E	Nitosols and Cambiosls	Volcanic(Basalts and tuffs)	Moist – cool and Sub-humid cold	Mixed agriculture	4.8	0.1	1.2	0.31	2.4	13.5	32.8	18.2	72.2	73.2	2.02
Fitoketemena, Southern Ethiopia, N 06° 55" 26' and E 38° 36" 21'	Orthoeutric Nitisol	Rhyolites, Trachytes, rhyolites and tracytic tuffs.	Sub-moist-tepid	Mixed cropping, intensive land use	5.4	0.045	0.36	2.3	2.8	24.3	31.5	29.2	84.9	64.1	0.45

Table 2. Descriptive statistics: pH-H_2O, EC(ms/cm), Exch.K (me/1, N%, OC%, Ava.P (ppm).

Variable	Mean	SE Mean	Variance	CoefVar	Minimum	Maximum
pH-H_2O	5.861	0.175	0.889	16.08	4.480	8.240
EC (ms/cm)	0.1462	0.0320	0.0298	118.00	0.0100	0.7500
Exch.K (me/100 g	0.960	0.111	0.360	62.49	0.340	2.300
N%	0.492	0.119	0.409	129.95	0.110	2.860
OC%	2.526	0.206	1.225	43.81	0.260	4.100
Ava.P (ppm)	24.00	1.66	79.70	37.19	11.20	41.00
CEC(meq/100 g soil)	33.653	0.718	14.955	11.49	24.800	47.500
Zn (ppm)	14.22	1.45	61.05	54.95	0.71	29.20
Fe (ppm)	72.23	3.54	362.67	26.37	27.00	109.70
Mn (ppm)	64.69	2.59	194.28	21.55	32.00	83.47
Cu (ppm	1.431	0.160	0.743	60.27	0.160	3.440