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Review on contribution of integrated soil fertility management for climate change mitigation and agricultural sustainability

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Abstract: Agriculture is one of the largest contributors to greenhouse gas emissions, derived from livestock farming (enteric fermentation and manure management) and emissions from agricultural soils (i.e. application of excessive N fertilizers and decomposition of organic material). The review covers contribution of integrated fertility management to mitigate climate change and sustain agricultural production. Combined application of farmyard manure and mineral fertilizer is very economical than sole NP application in maintaining sustainable agricultural productivity. Maximum sustained crop production (2.88 t/ha) was obtained when 69 kg of NP fertilizer was applied with 10 t/ha farmyard manure. Combined application of tie ridge, farmyard manure and NP fertilizer contribute for agricultural sustainability. Applying integrated soil fertility increase total nitrogen and available phosphorus in the soil for agricultural sustainability. The highest carbon (12 mg/kg) was sequestered when farmyard manure was applied with NP fertilizer on maize and wheat cropped alfisoils. Application of integrated fertility management reduces N_2O emissions by increase nitrogen-use efficiency. Application of animal manure and NPK fertilizer reduce CH_4 into the atmosphere contributing for climate change mitigation. Integrated soil fertility management improves soil fertility contributing

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PUBLIC INTEREST STATEMENT

Agriculture is the basic economic sector in which the country relies on for its social and economic development. In spite of the fact that 80% of the population has been employed in food production, it fails to feed relatively large proportion of population from its domestic production. In Ethiopia 83% of small-holder farmers participated in farming activities and only 27% were engaged in non-farm economic enterprises. Nonfarm employment provides additional income that enables farmers to spend more on their basic needs include food, education, clothing and health care. Food security exists when all people at all times have the physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for active and healthy life. Agriculture basically needs good soil, convenient environment, managed watershed and fair distribution of resources to the community.

for agricultural sustainability. Crop yield was improved by application of integrated fertility management which sustains agriculture. Integrated soil fertility management was on option for climate change mitigation.

Subjects: Agriculture; Environmental Sciences; Agriculture and Food

Keywords: climate change; soil fertility; agriculture; sustainability; crop yield

1. Introduction

1.1. Background and justification

The world's population is estimated to reach 9.2 billion by 2050. Over this period, agricultural production must increase by 70% to keep pace with increasing food demand (FAO, 2000). More than 95% of global food comes from land, so an adequate global food supply depends predominantly on the continued availability of productive soils. However, quality soils are not guaranteed without additional efforts (van Beek et al., 2014). In addition, ongoing climate change has increased alterations of weather patterns, affecting soil moisture availability and bringing associated consequences for diseases and pest incidences). By 2050, climate change is expected to negatively impact at least 22% of the cultivated areas of the world's important crops, notably rice and wheat (Campbell et al., 2011), and increase global warming. Global warming is caused by increased atmospheric concentrations of Greenhouse Gases (GHGs), mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2 O).

Agriculture is one of the largest contributors to GHG emissions, derived from livestock farming (e.g., enteric fermentation and manure management) and emissions from agricultural soils (i.e. application of excessive N fertilizers and decomposition of organic material). On average, agriculture accounts for about 14% of the total global GHG emissions (Parry, 2007). Contributing factors are poor land management by humans, such as over-cultivation, overgrazing and deforestation (), draining of peatlands and burning of rainforests.

Being part of the problem, agriculture is also part of the solution to climate change impacts. If agricultural soils are properly managed and effective policies are in place, they have the potential to sequester large amounts of carbon from the atmosphere and store it in the soils, thereby mitigating CH_4 and CO_2 emissions (Gaskel et al., 2007).

Soil fertility and plant nutrition are important components of plant production. Productive capacity of soils requires the provision of adequate and balanced amounts of nutrients to ensure proper growth of the plants. The fact on the ground is that, soil nutrient status of most farming systems is widely constrained by the limited use of inorganic and organic fertilizers and by nutrient loss mainly due to erosion and leaching (Balesh Tulema et al., 2007).

Nutrient management is one of the most important decision-making processes faced by those involved in the growth and production of plants for any purpose, whether it is as agronomic crops, as horticultural and landscape plantings in urban settings, or for the conservation and reclamation of disturbed lands.

Increasing the inputs of nutrients has played a major role in increasing the supply of food to a continually growing world population. However, over-application of inorganic fertilizers causes inefficient use, large losses and imbalances of nutrients. It also leads to environmental contamination in a number of areas in developed world. On the other hand, insufficient application of nutrients and poor soil management, along with harsh climatic conditions and other factors have

contributed to the degradation of soils including soil fertility depletion in developing countries like Sub-Saharan Africa (Goulding et al., 2008).

In an attempt to boost crop production, farmers use both mineral and organic fertilizers to increase the condition of crop growth. The demerits of both mineral and organic fertilizer lead to the innovation of a new fertilizer called organ mineral fertilizers or integrated nutrient management. Many experiments have been conducted with the use of combined organic and mineral fertilizers for crop production in different formulations. Akande et al. (2010) combined kola pod husk with NPK fertilizer for production of Amaranthus. Ayeni (2010) used combined poultry manure and NPK 20:10:10 fertilizer to increase the yield of maize and soil nutrients.

To replenish the soil nutrient depletion, application of chemical fertilizers is essential. However, high cost of chemical fertilizers coupled with the low affordability of small-holder farmers is the biggest obstacle for chemical fertilizer use. Moreover, the current energy crisis prevailing higher prices and lack of proper supply system of inorganic fertilizers calls for more efficient use of organic manure, green manure, crop residues and other organic sources along with the inorganic fertilizers to sustain the yield levels (Sathish et al., 2011).

However the application rate is often insufficient due to the low availability and high cost of mineral fertilizers. Further, problems with acidification may occur after intensive addition of ammonium-based N fertilizers (Vanlauwe and Giller, 2006). On the other hand, organic amendments show a slower nutrient release pattern than mineral fertilizer but facilitate an increased soil organic matter (SOM) content (Pinitpaitoon et al., 2011). Although (Vanlauwe and Giller 2006) claim that organic resources are not sufficient enough to supply crops with the required nutrients, the increased SOM is enhancing productivity due to the improved biological activity and physical soil properties (Watson et al., 2002).

Continuous uses of inorganic fertilizers lead to deterioration of soil chemical and physical properties, biological activities and thus in general the total soil health (Mahajan et al., 2008). Nutrients supplied exclusively through chemical sources, though enhance yield initially, lead to unsustainable productivity over the years (Mahajan et al., 2008; Satyanarayana et al., 2002). Thus the negative impacts of chemical fertilizers, coupled with their high prices, have prompted the interest in the use of organic fertilizers as source of nutrients. Organic fertilizer application has been reported to improve crop growth by supplying plant nutrients including micro-nutrients as well as improving soil physical, chemical, and biological properties thereby provide a better environment for root development by improving the soil structure (Dejene et al., 2011).

Furthermore, the price of inorganic fertilizers is increasing and becoming unaffordable for resource-poor small-holder farmers. The best remedy for soil fertility management is, therefore, a combination of both inorganic and organic fertilizers, where the inorganic fertilizer provides readily available nutrients and the organic fertilizer mainly increases soil organic matter and improves soil structure and buffering capacity of the soil (Alemu et al., 2015). The combined application of inorganic and organic fertilizers, usually termed as integrated nutrient management, is widely recognized as a way of increasing yield and/or improving productivity of the soil sustainably (Mahajan et al., 2008). Several researchers (Singh & Agarwal, 2001; Mahajan et al., 2008; Gafar et al., 2012) have demonstrated the beneficial effect of integrated nutrient management in mitigating the deficiency of several macro- and micro-nutrients. In view of this fact, identifying the optimum dose of integrated nutrients application is crucial and is required for maintaining adequate supply of nutrients for increased yield.

Integrated nutrient management (INM) is the combined use of mineral fertilizers with organic resources such as cattle manures, crop residues, urban/rural wastes, composts, green manures and bio-fertilizers (Antil, 2012). Its basic concept is sustaining soil and crop productivity through optimization of all possible sources of plant nutrients in an integrated manner. In this system, all aspects of mineral and organic plant nutrient sources are integrated into the crop production system FAO (Food and Agriculture Organization of the United Nations) (FAO, 2006) and are utilized in an efficient and judicious manner for sustainable crop production (A. Singh et al., 2012). It contributes in attaining agronomically feasible, economically viable, environmentally sound and sustainable high crop yields in cropping systems by enhancing nutrient use efficiency and soil fertility, increasing carbon sequestration, reducing nitrogen losses due to nitrate leaching and emission of greenhouse gases (FAO, 2006; Milkha & Aulakh, 2010).

Integrated nutrient management implies the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity on one hand and to minimize nutrient losses to the environment on the other hand. It is achieved through efficient management of all nutrient sources. Nutrient sources to a plant growing on a soil include soil minerals and decomposing soil organic matter, mineral and synthetic fertilizers, animal manures and composts, by-products and wastes, plant residue, and biological N-fixation (BNF) (Singh & Agarwal, 2001).

The diversity of agroecological zones (AEZs) across SSA (table) results in the wide range of farming systems. According to the availability of natural resources (land, water, grazing, areas and forest) and climate, especially length of growing period and altitude, as well as the pattern of farm activities and household livelihood, African farming systems can be classified into different farming classes.

2. Objectives

(1) General objective

The overall objective of the paper is to review on contribution of integrated fertility management for climate change mitigation and agricultural sustainability

(1) Specific objectives

The specific objective of the review was

- To review the contribution of integrated fertility management on climate change mitigation
- To review the role of integrated fertility management for agricultural sustainability
- To review the residual advantage of integrated fertility management

3. Literature review

Soil and climate change Soils are critical to food security, but are too slowly formed and too quickly lost. Since climatic variables such as rainfall and temperature play an important role in the formation and/or destruction of soils (Brady and Weil, 2007), we need to better understand the impact of climate change on soil processes and properties, and how soil management techniques contribute to climate change (CC) adaptations/resilience, reduction in GHG emissions and increase in agricultural productivity. Soil resilience refers to the magnitude of disturbance (caused by climate change in this case) that can be absorbed or accommodated before the system changes its structure (Seybold, 1999). The soil properties and functions that are closely related to soil resilience and mostly affected by CC are soil structure and texture, organic matter content, nutrient dynamics, soil organisms, soil pH and cation exchange capacity (Figure 1).

Figure 1. Carbon sequestration potential of soil.

Property	*CC adaptation and mitigation potential*
Soil texture and structure	If soil structure is damaged by tillage operations during wet-dry conditions, the soil texture/structure functions to retain water and nutrients are hampered, and consequently the resilience to CC is reduced (FAO, 2013).
Soil organic matter (SOM)	SOM reduces evaporation, improves infiltration, increases soil aggregate stability; provides nutrients upon mineralization; and reduces surface runoff. These SOM functions increase the required adaptation potential to CC, build up resilience to water stress, and help mitigate GHG emissions (Giller *et al*., 2009; FAO, 2013; Powlson *et al*., 2011).
Soil nutrients and organisms	Need-based N management reduces losses of N and increases efficiency. Organisms living in soils (like earthworms) make nutrients available for uptake by plants through active involvement in the transformation and decomposition of nutrients., Soil organisms enhance adaptation to CC impacts, and increase crop production (Varinderpal-Singh *et al*., 2012; Ali *et al*., 2015).
Soil pH	Higher temperatures and evaporation rates increase accumulation of salts in the topsoil thereby raise the pH levels. Under such conditions, salinity is intensified, and water and nutrient availability is hampered, and soil structure is degraded. On the other hand, substantial increase in rainfall, accompanied by leaching, could lead to increase soil acidity. In consequence, the activity of microorganisms and nutrient release to crop plants is reduced, asnd does soil resilience to CC (FAO, 2013).

Soils should be adequately monitored, protected and maintained in order to ensure that the above-mentioned crucial soil properties and functions remain in place. A range of soil management practices, including soil fertility improvements and soil erosion control, have been developed and applied by farmers and researchers in different parts of the world with a goal to achieve sustainable food security. However, a single soil management practice may solve part of the problem of CC impacts and food security, but not the whole problem. Understanding the status and condition of the soil properties is fundamental to making decisions to adopt or not to adopt soil management practices that contribute to climate-smart agriculture (CSA).

CSA is based on the simultaneous achievements of three principal objectives:

(i)adaptation to CC;

(ii)mitigation of GHGs emissions; and

(iii)increased agricultural productivity.

The need for integrated fertility management there is no universal definition adopted for Integrated Fertility Management (IFM). It all depends on the particular soil problem in the area. Therefore, there could be IFM for soil fertility improvements, ISFM for soil erosion control, and so forth. According to Simpson et al. (2014), ISM for soil fertility improvements is: a set of soil fertility management practices that entails the use of fertilizer, organic inputs and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity (figure 2).

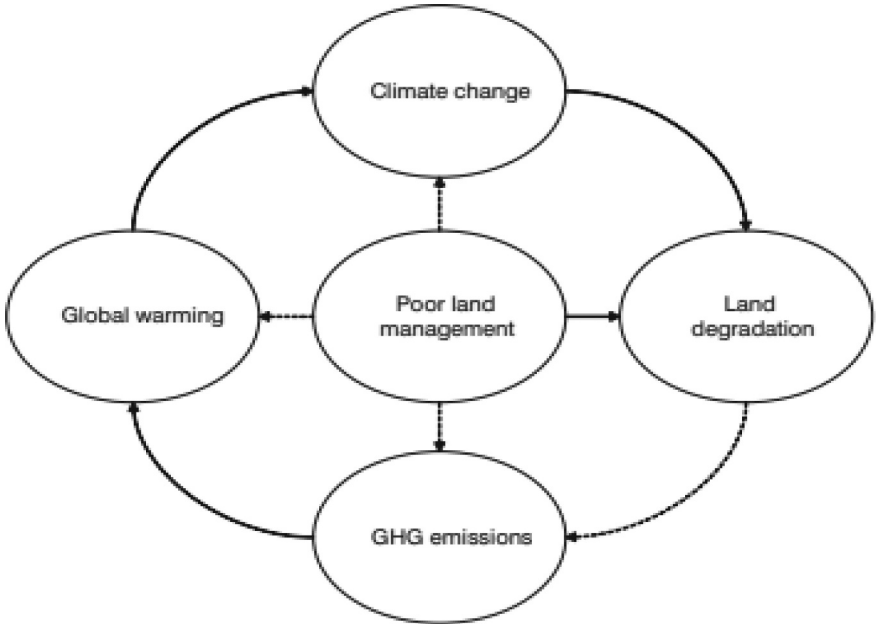

Figure 2. The relationship between climate change and soil management.

More than 30 years of research on soil fertility, crop nutrition and socioeconomics in smallholder farming systems of sub-Saharan Africa has shown that combined interventions on fertilizer and organic inputs are prerequisites for achieving sustainable intensification. Integrated Fertility Management (IFM) builds on this notion and is originally defined as: 'A set of soil fertility management practices that necessarily includes the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions in aim of maximizing the agronomic use efficiency of the applied nutrients and improving crop productivity. ISFM seeks that all inputs are managed following sound agronomic practices' (B. Vanlauwe et al., 2010). Any of the interventions is required to increase the efficiency and profitability of food production as related to use of land, labour, fertilizer inputs and financial investments.

Challenges to adoption of ISFM despite the significant benefits of IFM for food security, household income and environmental protection, the adoption of practices by farmers is usually low and incomplete, especially in African small-holder systems.

The most important factors curtailing adoption are related to: i) high transaction costs of input and produce trading (Alene et al. 2008), ii) low awareness and common disbeliefs about the benefits of soil fertility management (Schuijs et al. 2015), iii) shortage of credit facilities for making initial investments, iv) aversion to risks surrounding the profitability of inputs, v) cost and availability of labour (Roumasset & Lee 2007), vi) land size and property rights (Holden & bezabih 2008), vii) weak social networks and pervasive distrust (Wossen et al. 2015), viii) lack of information about soil fertility and rainfall forecasts (Maro et al. 2013), and ix) scarcity of organic residues and competition for residues with livestock (Giller et al. 2011).

4. Concepts of ISFM

Many paradigms on sustainable agriculture adhere to a combination of different and complementary agricultural technologies. Whether such a paradigm survives in practice depends on how farmers combine (or substitute) these technologies on their fields. Based on the work by Rauniyar

and Goode (1992), we classify interrelationships in the application of different technologies by farmers in three main categories: independent, sequential, or simultaneous. Technologies are independent if the probability of application of one technology is not conditioned by the adoption of another technology. Sequential adoption takes place when the probability of application is conditioned on the adoption of another technology that precedes it. Finally, simultaneous adoption occurs when the probability of applying one technology is conditional on the adoption of another technology (. The main biophysical rationale for farmers to combine different technologies is the existence of interaction effects on yield. Joint or sequential application of several technologies can have important non-linear effects, reducing or reinforcing the impact of a single technology on agricultural output, and/or leading to lasting effects on soil fertility and future productivity (B. Vanlauwe et al., 2010). For example, the agronomic efficiency of nitrogen (NAE) in inorganic fertilizers is shown to significantly improve in combination with manure, and similarly, NAE is significantly higher when applied on improved varieties (B. Vanlauwe et al., 2011).

Integrated soil fertility management (ISFM) is a means to increase crop productivity in a profitable and environmentally friendly way (B. Vanlauwe et al., 2010) and thus to eliminate one of the main factors that perpetuates rural poverty and natural resource degradation in sub-Saharan Africa (SSA). Current interest in ISFM partly results from widespread demonstration of the benefits of typical ISFM interventions at plot scale, including the combined use of organic manure and mineral fertilizers (Zingore et al., 2008), dual-purpose legume–cereal rotations (Sanginga et al., 2003), or micro-dosing of fertilizer and manure for cereals in semiarid areas (Tabo et al., 2007). ISFM is also aligned to the principles of sustainable intensification (Pretty et al., 2011), one of the paradigms guiding initiatives to increase the productivity of small-holder farming systems. Sustainable intensification, though lacking a universally accepted definition, usually comprises aspects of enhanced crop productivity, maintenance and/or restoration of other ecosystems services, and enhanced resilience to shocks. ISFM can increase crop productivity and likely enhances other ecosystems services and resilience by diversifying farming systems, mainly with legumes, and increasing the availability of organic resources within farms, mainly as crop residues and/or farmyard manure.

One of the principles of ISFM—the combined application of fertilizer and organic resources—has been promoted since the late 1980s (B. Vanlauwe et al., 2001a), because of (i) the failure of Green Revolution-like interventions in SSA and (ii) the lack of adoption of low-external-input technologies by small-holder farmers, including herbaceous legume-based technologies. The combined application of fertilizer and organic inputs made sense since (i) both fertilizer and organic inputs are often in short supply in small-holder farming systems due to limited affordability and/or accessibility; (ii) both inputs contain varying combinations of nutrients and/or carbon, thus addressing different soil fertility-related constraints; and (iii) extra crop produce can often be observed due to positive direct or indirect interactions between fertilizer and organic inputs (B. Vanlauwe et al., 2001a). In 1994, Sanchez (1994) presented the “second paradigm” for tropical soil fertility management, to “overcome soil constraints by relying on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity, and optimizing nutrient cycling to minimize external inputs and maximize their use efficiency”. In this context, he already highlighted the need to integrate improved germplasm, a second principle of ISFM, within any improved strategy for nutrient management.

Integrated soil fertility management aims at the optimal and sustainable use of soil nutrient reserves, mineral fertilizers and organic amendments as well as improved germplasm. Combining increases crop yield and rebuild depleted soils and protect the natural resource base and focuses on application of locally adapted SFM practices (B. Vanlauwe et al., 2001a).

5. Principles of ISFM

Maximize use of organic materials; Organic inputs (crop residues and animal manures) are also an important source of nutrients, but their N, P, Mg and Ca content is only released following decomposition. By contrast, K is released rapidly from animal manures and crop residues because it is contained in the cell sap. Further, the amount of nutrients contained in organic resources is usually insufficient to sustain required levels of crop productivity and realize the full economic potential of a farmer's land and labour resources (Alun, 2020).

Judicious use of inorganic fertilizer; Mineral fertilizers are required to supplement the nutrients recycled or added in the form of crop residues and animal manures. Fertilizers are concentrated sources of essential nutrients in a form that is readily available for plant uptake. They are often less costly than animal manures in terms of the cost of the nutrients that they contain (i.e. $/kg nutrient) but often viewed as more costly by farmers because they require a cash outlay (Alun, 2020).

Use of improved germplasm; It is important that the farmer uses the crop planting materials (usually seed but sometimes seedlings) best adapted to the particular farm in terms of (Alun, 2020):

- Responsiveness to nutrients (varieties differ in their responsiveness to added nutrients);
- Adaptation to the local environment (soils, climate); and
- Resistance to pests and diseases (unhealthy plants do not take up nutrients efficiently).

6. Effect of ISFM for soil fertility improvement

Soil fertility can be defined as the capacity of soil to provide physical, chemical and biological needs for the growth of plants for productivity, reproduction and quality, relevant to plant and soil type, land use and climatic conditions (Abbott & Murphy, 2007). It is becoming understandable that the proper agricultural use of soil resources requires equal consideration for biological, chemical and physical components of soil. Soil fertility is, thus attaining a sustainable agricultural system.

First step in maintaining soil fertility should be directed at maintaining the organic matter content of the soil. This can be done by using appropriate crop husbandry practices and by applying organic manure or compost together with mineral fertilizer. Chemical fertilizers can restore the soil fertility very quickly whereas organic fertilizers will provide nutrients to the soil in slow way (Laura & Rienke, 2004).

It is generally known that the incorporation of fertilizers is increasing yield and agricultural productivity. The combination of both, organic and mineral fertilizers is crucial as they influence different soil properties. Mineral fertilizers are characterized by a high concentration of plant-available nutrients. Several studies showed a significant increase of grain yield after mineral fertilizer treatment. Drechsel et al. (2001) is claiming that fertilizer application is increasing with increasing population pressure at small-holder level. At small-holder level organic material is applied in form of farmyard manure (FYM) as it is often the source of organic matter (Dunjana et al., 2012).

6.1. Residual advantage of integrated soil fertility management

Reviewing the residues of fertilizers on succeeding crops, Cooke (1970) reported that past manuring with farmyard manure and fertilizers leaves residues of nitrogen, phosphorus and potassium in soil that benefit following crops. He further indicated that the residues of inorganic nitrogen fertilizers usually last only for a season, but the residual effects of continued manuring with phosphorus and potassium may last for many years.

Akande et al. (2003) also reported an increase in soil available P of between 112% and 115% and 144% and 153% respectively for a two-year field trial, after applying rock phosphate with poultry manure on okra. Akande et al. (2005) further reviewing the effect of rock phosphate amended with poultry manure on the growth and yield of maize and cowpea reported that when rock phosphate application had continued over a period of several years a large pool of undissolved rock phosphate could accumulate.

Residual effects of manure or compost application can maintain crop yield level for several years after manure or compost application ceases since only a fraction of the N and other nutrients in manure or compost become plant available in the first year after application (Eghball, 2002). Eghball and Power (1999) found that 40% of beef cattle feedlot manure N and 20% of compost N became plant available in the first year after application, indicating that about 60% of manure N and 80% of compost N became plant available in the succeeding years, assuming little or no loss of N due to $NO3^{-}$ leaching or denitrification. Residual effects of organic materials on soil properties can contribute to improvement in soil quality for several years after application ceases (Ginting et al., 2003).

Cooke (1970) found that 184.8 kg Nitrogen ha^{-1} given to potatoes raised yields of wheat the following year which received no fresh fertilizer nitrogen from 3463.8 to 4570.5 kg ha^{-1}, but even where the wheat received a fresh dressing of 123.2 kg N ha^{-1}residues from the dressing given to the previous potatoes still raised yields by 764.5 kg ha^{-1}. Further results showed that when soil contains residues of inorganic nitrogen, larger maximum yields are possible than may be obtained from soil without residues. The results also showed that dressings of inorganic N fertilizers had large residual effects in the first year after the dressings stopped but much smaller effects in the second and third years.

Manure fertilizer treatments had beneficial residual effects on crop production and use from manure fertilizer for field fertilization and production of crops was better improved. Significantly high grain was obtained from residual application of 8 t ha^{-1} and is proportional with existing fertilizer recommendation. Therefore for resource poor farmers combined application of farmyard manure and mineral fertilizer is very economical than sole NP application (Assefa, 2015).

A study conducted at Ethiopia using nug as proceeding crop indicted that maize grain yields were significantly increased in rotation with this crop compared to the continuous cropped maize (figure 3).

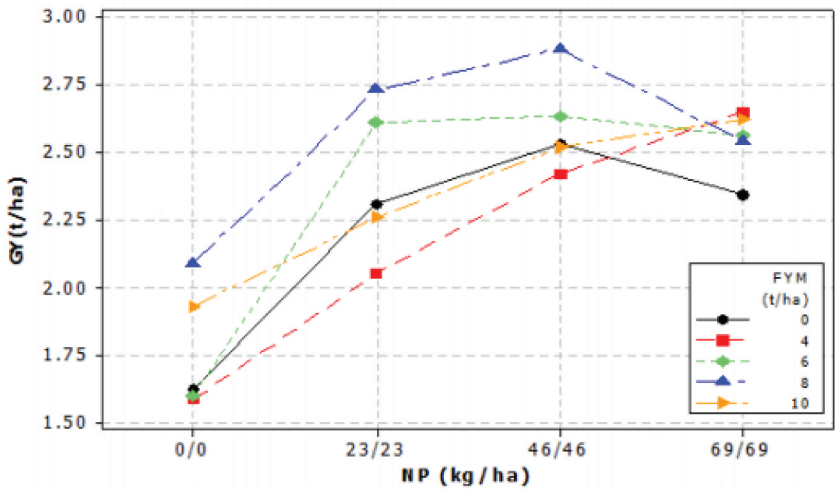

Figure 3. Residual effect of farm yard manure on grain of barley.

This result clearly demonstrated the residual benefits of crop rotation with reduced NP fertilizer amendments and enhanced maize grain yield. Also the integrated use of precursor crops with low rate of NP and farmyard manure gave comparable maize yield to a plot received recommended fertilizer rate (110/20 kg NP ha-1). Production of maize following nug as a precursor crop by integrating with 46/5 kg ha-1 NP and 8 t FYM ha-1 could be affordable for small-holder farmers in Ethiopia areas (Berhanu, 1985).

Means with the same letter in the same column are not significantly different at 5% using Duncam Multiple Range Test

The possible reason for maximum height in FYM or VC (vermiy compost) plus mineral NP treatment might be that the mineral NP sources fulfilled the NP requirements at early growth stages while farmyard manure and vermicompost provided the crop with maximum nutrients in later stages.

Thus, combination of (FYM + inorganic NP and VC + inorganic NP) might have nourished the crop in initial stages as well as in the later growth stages. The result of this experiment agreed with the finding of Amanuliah and Maimoona (2007) who reported that the use of increased rates of FYM and N increased plant height of wheat and the shortest plants recorded from the control treatment. Also in agreement with this result, Ofosu and Leitch (2009) reported that plant height of spring barley increased with organic manure application as compared to inorganic fertilizer alone. Similarly, Getachew reported that the use of organic manures in combination with mineral fertilizers maximized the plant height than the application of inorganic fertilizers alone (Table 1).

Generally, it was observed that except the combined application of 2.5 t ha^{-1} VC with 25% and 50% inorganic NP fertilizers both at Adiyo and Ghimbo, the combined application of organic and inorganic fertilizers have resulted in higher aboveground biomass yield than the application of 100% recommended rate of inorganic NP alone. This implies that integrated use of organic and inorganic fertilizers responded better to increase productivity than the use of inorganic fertilizer alone in the study areas. Likewise, Shata et al. (2007) suggested that by the use of mixed chemical and bio-fertilizers not only production can be kept at optimum level, but also the amount of

Table 1. Major farming systems in sub-Saharan Africa

Farming system	Percent of land	Principal crop
Integrated	9	Rice, cotton, vegetables, rainfed crops, cattle, poultry
Tree crop	18	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work
Forest based	14	Cassava, maize, beans, cocoyams
Maize mixed	33	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work
Agro pastoral	8	Sorghum, pearl millet, pulses, sesame, cattle, sheep, goats, poultry, off-farm work
Pastoral	17	Cattle, camels, sheep, goats, remittances
Urban based	1	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work

Source FAO; 2016

chemical fertilizer to be used can be reduced. Plant bio-chemical activities improve by absorption of nutrients from soil and this increases the grain yield and biological yield plant^{-1}.

Research on wheat and tef revealed that the application of different soil fertility management treatments significantly ($p < 0.05$ and $p < 0.01$) affected organic carbon, total N, available P, nitrate N (NO_3-N) and ammonium N (NH_4-N) analyzed for samples taken after harvesting from trial fields of both crops. Soil pH of wheat fields was significantly ($p < 0.05$) affected by different soil fertility management treatments, but not soil pH of tef trial sites (Tables 2 and 3). Different soil fertility management treatments had significant effects on post-harvest soil organic carbon content. A significant improvement was observed in organic carbon content compared to the contents of the soil before treatment application. Relatively higher soil organic carbon was recorded on experimental plots, which received either organic or inorganic and organic nutrient sources (Tables 2 and 3) than plots received only inorganic fertilizers (Agegnehu et al., 2014).

6.2. Effect integrated soil fertility management on climate mitigation

Healthy soils provide the largest store of terrestrial carbon. When managed sustainably, soils can play an important role in climate change mitigation by storing carbon (carbon sequestration) and decreasing greenhouse gas emissions in the atmosphere. Conversely, if soils are managed poorly or cultivated through unsustainable agricultural practices, soil carbon can be released into the atmosphere in the form of carbon dioxide (CO_2), which can contribute to climate change. The steady conversion of grassland and forestland to cropland and grazing lands over the past several centuries has resulted in historic losses of soil carbon worldwide. However, by restoring degraded soils and adopting soil conservation practices, there is major potential to decrease the emission of greenhouse gases from agriculture, enhance carbon sequestration and build resilience to climate change (FAO, 2015).

Soil hosts the largest terrestrial carbon pool, and the biogeochemical processes that take place in the soil regulate the exchange of greenhouse gases with the atmosphere (Scharlemann et al., 2014). These processes and emissions are strongly affected by land use, land-use change, vegetation cover and soil management (Chapter B7-2.1). The stocks of soil organic carbon in the upper soil layers are particularly responsive to these influences, and their careful management provides an opportunity to reduce the concentration of greenhouse gases in the atmosphere.

Table 2. Maize productivity along different treatment (Adapted from: Vanlauwe, Unpublished data)

Plant height (cm)	No. of leaves (cm^2)	Leaf area (t/ha)	Stover yield (t/ha)	Grain yield (t/ha)	Root dry (%)	Matter	Increase in grain
Control	72.60e	8.00 c	14d	3.23 c	2.84 c	0.67b	-
2.5 t/ha OG	89.70e	9.33bc	20 c	3.59 c	3.00b	0.93a	5.63
5 t/ha OG	107.90d	9.23 c	19 c	3.97bc	3.11b	0.97a	9.51
10 t/ha OG	149.40 c	12.00b	32b	4.99b	4.25a	0.99a	49.65
2.5 t/ha OMF	129.40 c	12.20b	44a	5.34a	4.55a	1.10a	60.21
5 t/ha OMF	169.20b	14.59a	31b	5.36a	4.78a	1.00a	68.31
10 t/ha OMF	164.10b	12.40b	30b	4.63b	3.94a	0.97a	38.72
300 kg/ha NPK	194.00a	12.3b	24 c	4.23b	3.44ab	0.93a	12.13

Table 3. Effect of integrated soil fertility management on soil properties

Treatments ($kgha^{-1}$)	pH (H_2O)	OC (%)	N (%)	P (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)
Control	5.57	1.36	0.14	9.4	6.00	8.55b
Farmers NP rate (23/10/0)	5.36	1.61	0.16	11.00	6.33b	9.25
Recommended NP rate(60/20/0)	5.26	1.83	0.17	15.55	7.20	9.78
50% of recommended NP rate+50% manure + 50% of compost as N equivalence	5.76	2.06	0.18	15.57	10.60	13.60
50% of manure +50% of compost as N equivalence	6.15	1.98	0.17	15.52	9.78	10.70
F-probability	*	**	*	**	**	*
$LSD_{0.05}$	0.39	0.21	0.02	3.40	1.82	2.97
CV (%)	4.55	13.2	2.69	16.40	14.81	18.61

Source; (Agegnehu et al., 2014).

Sustainable soil and land management interventions that are designed to increase soil organic matter should be accompanied by actions that address the drivers of degradation and help preserve existing soil carbon stocks, particularly in soils with high soil organic carbon content (Smith et al., 2014).

Carbon sequestration in soils will contribute to climate change adaptation and mitigation. It will also make agricultural production systems more sustainable; increase the overall resilience of agricultural ecosystems; and maintain the ecosystem services that are supported by soils (FAO (Food and Agriculture Organization of the United Nations), 2006).

Healthy soils provide the largest store of terrestrial carbon. When managed sustainably, soils can play an important role in climate change mitigation by storing carbon (carbon sequestration) and decreasing greenhouse gas emissions in the atmosphere. Conversely, if soils are managed poorly or cultivated through unsustainable agricultural practices, soil carbon can be released into the atmosphere in the form of carbon dioxide (CO_2), which can contribute to climate change. The steady conversion of grassland and forestland to cropland and grazing lands over the past several centuries has resulted in historic losses of soil carbon worldwide. However, by restoring degraded soils and adopting soil conservation practices, through integrated fertility management there is major potential to decrease the climate change (Sainju et al., 2008).

A substantial amount of global CO_2 comes from soil through decomposition, mineralization and soil respiration. So when fertilizers were added to the soil through integrated way the decomposition rate was reduced and carbon dioxide emission was altered (Jabro et al., 2008).

Nutrient management strives to balance the withdrawal of soil nutrients from fields, pastures and orchards by crops, livestock and natural processes with the addition of nutrients provided by crop residues, compost, manure or commercial fertilizers. The main objective of nutrient management is to optimize the yield and quality of crop production, while minimizing costs and negative environmental

impacts. Failure to properly manage nutrients results in poor nutrient use efficiency and potentially harmful downstream environmental effects. Good nutrient management prevents the over-application of essential crop nutrients and sustainable nutrient management considers the full cost associated with application, including the energy embedded in added nutrients (Allen, 2011).

Climate change mitigation involves reducing the amount of greenhouse gases in the atmosphere or enhancing their sinks, e.g., by reducing the use of fossil fuels, planting trees, or enhancing mineralization of organic matter into soil organic carbon (John et al., 2014).

Adopting the INM strategy is essential to SOC sequestration. The sink capacity of SOM for atmospheric $C0_2$can is greatly enhanced when soils are treated with integrated nutrient management instead of treating it with organic or inorganic source of nutrient (Lal, 2004a).

World cropland soils cover about 1.5 b ha and have a large capacity to sink carbon (Lal, 2010). Management of soil organic carbon pool is an important aim to achieve adaptation to and mitigation of global climate change (Hansen et al., 2008), while advancing global food security (Lal, 2004b). As an important sink of carbon, cropland soils can be used to mitigate and adapt to global climate change. The rate and total magnitude of soil organic carbon sequestration (an average of about 0.55 × 10–9 Pg C ha-1 y-1; West and Post, 2002) depend on residue management and recycling of organics, climate regime, N application and soil properties. Similar to cropland soils, forest and grassland soils can also be important for carbon sequestration.

Many factors are involved in carbon sequestration in forest soils, including carbon input by litter and roots into different soil horizons, soil age, N application, moisture regime, site management, frequency and intensity of burning and the addition of charcoal and residue management (Lal, 2005a, 2005b). McKinsey and Company (2009) estimated that by 2030, afforestation can mitigate 0.27 Pg C yr −1; reforestation, 0.38 Pg C yr −1 and improved management, 0.08 Pg C yr −1. Grassland soils cover 2.9 b ha globally, including 2.0 b ha under tropical grasslands or savannas and 0.9 b ha under temperate grasslands (Lal, 2010). Possible management practices for C sequestration in grassland can be fertilization, controlled grazing, conversion of degraded cropland and native vegetation to pasture, sowing of leguminous and grass pasture species, fire management and water conservation. Mean rate of soil C sequestration in grassland is 5.4 × 10–10 Pg C ha-1 yr −1 (Conant et al., 2001).

7. Improving Nitrogen-Use Efficiency

The most effective method for reducing N_2O emissions is to increase nitrogen-use efficiency (NUE) by applying precise amounts of nitrogenous fertilizer with manure to crops based on N estimates from soil and plant tissue tests. Precisely timing N fertilizer applications will also increase NUE, ultimately leaving less N in the soil available for microbes to break down and release as N2 O. Accurate timing will also reduce fertilizer N losses due to nitrate (NO3) leaching (FAO, 2010).

8. INM reduce emission of GHG by

- Use recommended rates of suitable organic and inorganic fertilizers.
- Place the nitrogen more precisely into the root zone to make it more accessible by crops.
- If possible, use precision agriculture techniques to improve fertilizer application by helping determine exactly where to place nutrients, how much to apply, and when to apply.

Three techniques can help achieve this objective:

- The collection of spatial data from pre-existing conditions in the field (e.g., remote sensing, canopy size, or yield measurement);
- The application of precise fertilizer amounts to the crop when and where needed; and
- The recording of detailed logs of all fertilizer applications for spatial and temporal mapping.

Improvement in soil fertility through nutrient management is also important to SOC sequestration (Lal, 2005) because concentrations of SOC and N are key indicators of soil quality and productivity through their favourable effects on physical, chemical, and biological processes, including nutrient cycling, water retention, root and shoot growth, and environmental quality (Sainju and Good, 1993).

8.1. Effect of integrated soil fertility management on agricultural sustainability

The efficiency of applied chemical fertilizers is also increased when applied along with organic manures. Therefore, better management of soil nutrients is required that delivers sustainable agriculture and maintains the necessary increases in food production while minimizing waste, economic loss and environmental impacts (Goulding et al., 2008). Various long-term research results have shown that neither organic nor mineral fertilizers alone can achieve sustainability in crop production. Rather, integrated use of organic and mineral fertilizers has become more effective in maintaining higher productivity and stability through correction of deficiencies of primary, secondary and micronutrients (Milkha & Aulakh, 2010). Therefore, judicious use of integrated nutrient management is best alternative to supply nutrient to crop needs and improve soil conditions (Naresh et al., 2013).

So far, many research findings have shown that neither inorganic fertilizers nor organic sources alone can result in sustainable productivity (Satyanarayana et al., 2002).

For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer (figure 4). Research has shown that that combinations of organic

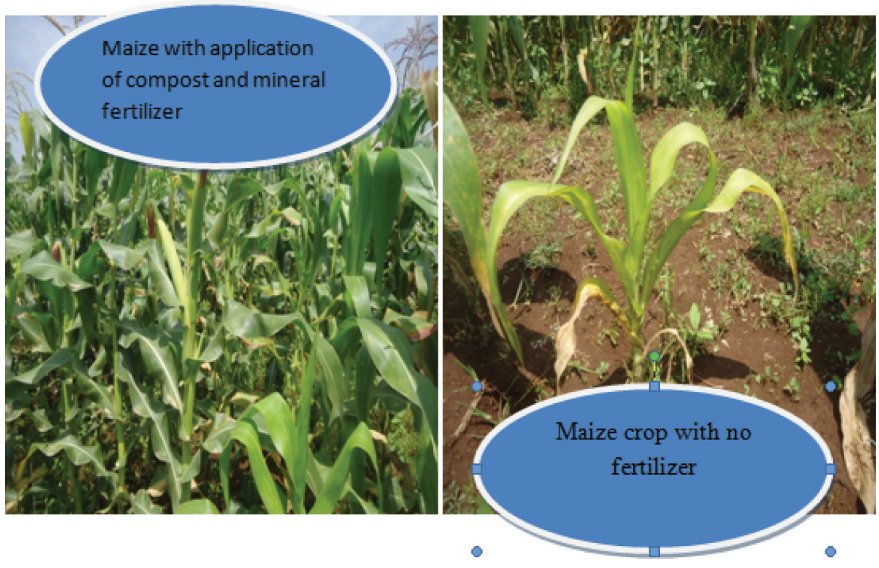

Figure 4. Effect of INM on sustainable crop growth.

and mineral fertilizers result in greater crop yields compared with sole organic or sole mineral fertilizers (Chivenge et al., 2009). B. Vanlauwe et al. (2002) reported that grain yield increases of up to 400% over the control in cases where the control yields are low. This increase in grain yield has been attributed to improved N synchrony with combined inputs through direct interactions of the organic and N fertilizers.

Figure 1.8 shows that the effect of integrated fertility management on overall performance of maize crop (Chivenge et al., 2009).

8.2. Effect of Integrated soil fertility management on crop productivity

The weakness in the productivity of crops across sub-Saharan Africa is not only related to the poor soils in many countries (Assefa, 2015) but also to the limited use of essential inputs that are needed to raise the productivity level. These inputs include the use of improved seeds, fertilizers, irrigation, pesticides. The hypothesis is that the use of these inputs would boost the productivity of crops (Alun, 2020).

Research results indicated that productivity of wheat was significantly affected by different soil fertility treatment levels. Applications of inorganic and organic nutrient sources either alone or in combination had a significant ($p < 0.001$ and $p < 0.01$) effect on grain yield, total biomass and harvest index of wheat, but not on its thousand grain weight (figure 5). Analysis of variance over two years indicated that the year by soil fertility treatment level interaction (YxT) effect was significant ($p < 0.05$ and $p < 0.001$) for wheat grain yield, total biomass and harvest index; but not for thousand grain weight (Agegnehu, 2016).

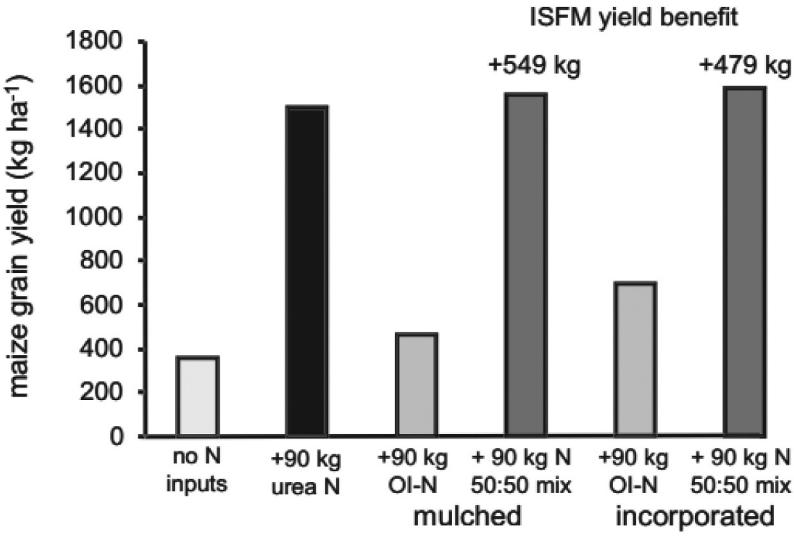

Figure 5. Interaction between mineral fertilizer and farmer available organic input(OI).

Source (B. Vanlauwe et al., 2010)

8.3. Effect of Integrated soil fertility management on environmental sustainability

The soil sustains most living organisms, being the ultimate source of their mineral nutrients. Good management of soils ensures that mineral elements do not become deficient or toxic to plants, and that appropriate mineral elements enter the food chain. Soil management is important, both directly and indirectly, to crop productivity, environmental sustainability, and human health. Because of the projected

increase in world population and the consequent necessity for the intensification of food production, the management of soils will become increasingly important in the coming years. To achieve future food security, the management of soils in a sustainable manner will be the challenge, through proper nutrient management and appropriate soil conservation practices. Research will be required to avoid further degradation of soils, through erosion or contamination, and to produce sufficient safe and nutritious food for healthy diets (Philip et al., 2012).

Long-term sustainability of agro ecosystems requires soil protection from degradation and reduction of greenhouse gas emissions and of environmental pollution. Soil protection needs judicious and prudent use of conservation agriculture to prove its potential as a conservation effective technology, climate-resilient agriculture, and a viable option for sustainable intensification of agro ecosystems for advancing food security and for adaptation to/mitigation of climate change. Conservation agriculture refers to a farming system comprised of crop residue mulch, cover cropping, integrated nutrient management (INM), and no tillage techniques in a rotation cycle for effective soil and water conservation, carbon sequestration, sustainable intensification and climate change adaptation and mitigation (Lal, 2015).

Soils host a huge biodiversity of microbes and fauna which is not yet well understood: the small size of the soil-borne organisms; their immense diversity; the difficulty in isolating them; and the great heterogeneity of their habitats across different scales. The soil biodiversity studies include microbes (archaea, bacteria, fungi) and fauna (protozoa, micro-arthropods, nematodes, oligochaeta), and their relation with above-ground biodiversity. We need to extend our capability to explore biological dynamics of soils at the scientific level, increase our knowledge of soil biodiversity and its role in ecosystem services across different soils, climate types and land uses at the technological level, standardize methods and operating procedures for characterizing soil biodiversity and functioning, and develop bio-indicators at the economic level, assess the added value brought by cost-effective bio-indicators, and cost effectiveness of alternative ecosystem services maintenance policies. For improving soil biological properties we need to deploy our efforts with three approaches: description of soil biodiversity and of the relations between soil biodiversity, soil functions and ecosystem services; long-term observatories representative of soil types, climates and land uses, and modelling to elucidate relationships between soil biodiversity and functions (Jahangir et al., 2018).

9. Conclusion

From the review of different literature the following points are concluded.

- From the review it is possible to conclude INM improves yield and yield components for different crops.
- INM is more advantageous than other soil fertility management methods due to residual nutrients that help to produce crop more than one season.
- INM is also important to mitigate climate change by increasing carbon sequestration and increasing N- use efficiency.
- Additionally INM plays a role in substantiality of agricultural productivity and soil fertility.
- Now a day's INM is becoming a soil fertility and yield improving practice in some parts of Ethiopia

10. Personal argument

Based on the review this is my arguements

- INM is best in its role on soil fertility and yield improvement in sustain way
- Especially for countries like Ethiopia integrating all nutrient source is very good to minimize the economic pressure on household income
- It is also very good b/c of its residual effect

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