Advances in Bioscience and Bioengineering
2020; 8(2): 17-23
http://www.sciencepublishinggroup.com/j/abb
doi: 10.11648/j.abb.20200802.12
ISSN: 2330-4154 (Print); ISSN: 2330-4162 (Online)

Review Article

Integrated Use of Soil Ameliorants and Fertilizers to Increase Crop Yield on Acidic Soils of Ethiopian Highlands

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To cite this article:
Mekonnen Asrat. Integrated Use of Soil Ameliorants and Fertilizers to Increase Crop Yield on Acidic Soils of Ethiopian Highlands. *Advances in Bioscience and Bioengineering*. Vol. 8, No. 2, 2020, pp. 17-23. doi: 10.11648/j.abb.20200802.12

Received: May 21, 2020; **Accepted**: June 2, 2020; **Published**: July 28, 2020

Abstract: Agriculture has been contributed great share for Ethiopian economy. Ethiopian highlands endowed suitable climatic conditions for crop production, however land degradation in terms of soil acidity and nutrient depletion is becoming the major limiting factor to improve crop yield. Most farmers of Ethiopian highlands are resource poor, small-scale holder, in contrary most crop land characterized by severely eroded and nutrient depleted by interaction effect of environmental conditions and human activities. Around 130 tons/ha soil has been removed from cultivated land, annually besides 40% of the arable land of the country are characterized by acidic soils. To improve crop yield combining use of soil amelioration and fertilization management is critical in such problematic area. Thus, integrated use of 2-3 t/ha lime and NP mineral or organic fertilizers significantly increased crop yield in acidic soils of the country. However, high application rate (11-12 t/ha) of biochar or wood ash on acidic soils has showed equivalent crop yield response to lime rate, hence therefore poor resource farmers can able to ameliorate acidic soils by cheaper and local available materials.

Keywords: Biochare, Fertilizer, Integrated, Lime and Nutrient Depleted

1. Introduction

Ethiopian highlands, areas with altitudes above 1500 masl cover about 500,000 km^2 it accounts about 45% of the landmass of the country [1]. The area has beencontributing 95% of the cultivated land, 90% of the economic activities and home for 88% of the population and 67% livestock of the country [2, 3]. However, the productivity of crop and per capital food production has been declined due to intensive soil fertility depletion in the area [4]. As a result, Ethiopia is frequently affected by food shortages; on average 5 million people require food aid each year. Since 1980s, the country could increase its grain production by 70%, but at the same time total population rose from 40 to 77.1 million and in next 25 years it will further increase by 31 million to 108.7 million [5].

As per [6] report revealed that a series of production failures since the 1970s in Ethiopia have resulted in chronic food insecurity. The causes for food insecurity and poverty may include demographic trends, recurrent drought, widespread land degradation, shrinking and fragmentation of landholdings, inappropriate policies, poor infrastructure and inefficient agricultural practices [7].

However, soil fertility degradation has been described as the single most important constraint to food security in Sub Saharan Africa (SSA) [8]. Land degradation problem mainly resulting from soil erosion and nutrient depletion, can be singled out as the most important environmental problems creating an unprecedented threat to food security goals of Ethiopia [7]. Most land degradation caused by great pressure from human and livestock populations coupled with other physical political and economical situation of Ethiopian highlands [9]. Most human interference for pursuing economic benefits contributes to rapid and extensive degradation of soils over the past half a century [10]. As per [11] report revealed that 26 percent of the land area in Ethiopia has been degrading over the years 1981-2003, directly affecting the livelihoods of about 29 percent of the population in the country.

Ethiopian agriculture is characterized by smallholder production [12]. One of the major constraints to crop production faced by smallholder subsistence farmers is inadequate supply of nutrients [13]. Land degradation through soil nutrient depletion in Ethiopia is arising from continuous cropping together with removal of crop residues, low external inputs and absence of adequate soil nutrient saving and recycling technologies [14].

On the other hand, usage of chemical fertilizer in Ethiopia is lower (69.8kg/ha) in terms of application rate per hectare of cultivated land due to various constraints but mainly by economical problem (dominant resource poor farmers) [15]. The use of chemical fertilizers to improve soil fertility of farmland in Ethiopia is low; usually less than 20 kg (N–P) ha^{-1} y^{-1} compared to world-wide rate of 97 kg ha^{-1} y^{-1}, and the fertilizer use is often restricted to irrigated land [16]. As per [17] report indicated that wheat accounted for the largest share (57 kg/ha), and followed by teff (40 k/ha) and maize (29 k/ha), respectively as compared to blanket recommended rate of 200 kg per ha.

Therefore, it is essential to look for agricultural practices that minimize degradation problem and at the same time increase agricultural productivity [7]. Integrated use of soil fertility inputs to alleviating the availability of nutrients problem [18]. On other hand, integrated nutrient management paradigm acknowledges the need for both organic and inorganic material inputs to sustain soil health and crop production due to positive interactions and complements between them [19].

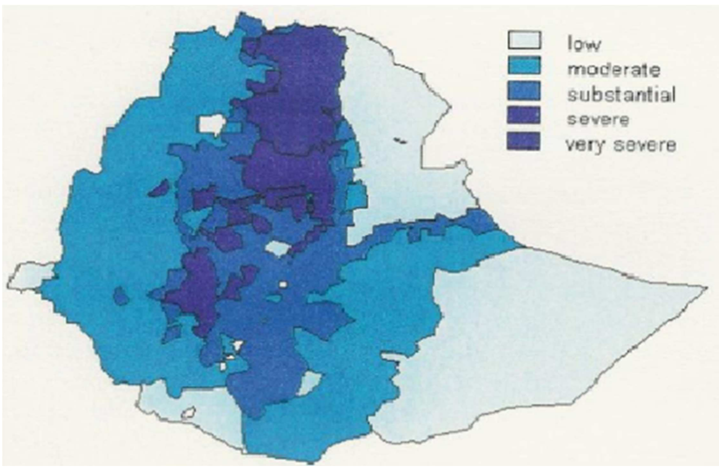
Integrated soil fertility management (ISFM) through provision of optimum fertilizer and soil ameliorants should be coupled with availability of credit facilities contribute to increased access to improved technologies. On the other hand, some recent empirical studies indicated that incorporating use of manure and modest amounts of fertilizers are important to increased and sustained crop yield and becoming more acceptable in smallholder farmers area through considering the economical problem of resource poor farmers [20]. Moreover, the combining use of organic and inorganic nutrient inputs is better option for increasing fertilizer use efficiency and crop yield [21]. The study conducted on *Ferralsols of* Kenya indicated that integrated use of TSP or Minjingu Rock Phosphate (MRP) with Tithonia significantly increased maize grain yield and alleviate land degradation problem [22].

However, the effectiveness of soil fertility interventions in Ethiopia has historically been constrained by the success in individual programs rather than integrated use of program. Historical evidence in Ethiopia supports the conclusion that the focus on fertilizer to date has been impressive but regrettably has not led to a revolutionary change in yields. Despite a five times increase in fertilizer application, cereal yields have only increased 10 percent since the 1980s [23].

2. Intensity and Valuation of Soil Degradation in Ethiopian Highlands

Soil erosion in agriculture is the most important problem in Ethiopia [24]. Ethiopian highlands soils are severely exposed to water erosion which accounts 130 tons/ha/yr for cropland and 3.4 to 84.5 tons/ha/year soil loosed from all land uses [25] (Figure 1). The problem of accelerating land degradation is especially serious in the intensively cultivated highland parts of the country [26]. Water erosion was the most important process and that in mid 1980's 27 million ha or almost 50% of highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation [27].

Soil erosion is estimated to reduce food production by at least 2 percent annually [28]. However, the direct losses of productivity from land degradation are minimally 3 percent of agriculture GDP. With a population growth rate of 2.3 percent this is a critically important [27]. Thus, land degradation has reached a severe stage and has become a major root cause of poverty with significant negative impacts on the country national economy [29]. The direct cost of loss of soil and essential nutrients due to unsustainable land management is estimated to be about three percent of agricultural GDP or $106 million [27]. As per [30] report estimated that water erosion reduces the potential land for crop production by 10% by 2010 and 30% by 2030 as a result agricultural value per capita drops from $372 U.S. in 2000 to $162 in 2030.



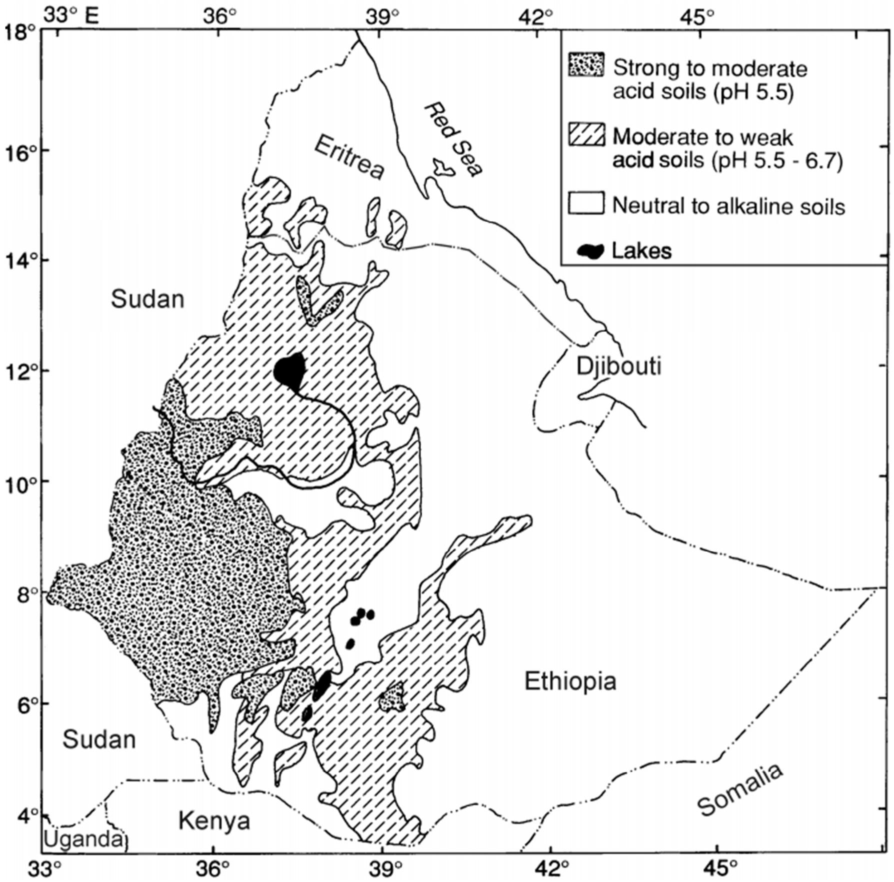
Source: Leonard, 2003

Figure 1. *The extent and intensity of soil degradation.*

The loss of nutrients in Ethiopia is very high more than 60 kg N, P and K ha^{-1} yr^{-1} (47 - 60 kg N, -15 kg $P_2 0_5$ and -38 kg K_2O ha^{-1} [31 32]. On the other hand acid soil infertility is a major limitation to crop production on highly weathered and leached soils of the world. Likewise, about 30% of the highly weathered soils of Ethiopia have been reported to be acidic and it is becoming a serious threat to cereal crops Ethiopian highlands' soils are characterized with low in organic matter content but high in acidity problem due to low land cover [33]. Soil organic matter is derived from decomposed plant and animal residues. Soil acidity is one of the major soil chemical constraints which limit agricultural productivity in the mid and highlands of Ethiopia. Most productive soils have pH in the range of 5.5 to 7.5 while soils with < 5.5 pH categorized in acidic reaction [34]. As per [35] report indicated that 40 percent potential arable land of the country is occupied by acid soils. Out of this, some 15 percent are highly acidic and visible in the west, southern, south-western and northwestern parts of Ethiopia (Figure 2). Soil acidity and its problem are common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface. The strongly acid soils are found in ecology which receive or have historically received high incidence of rainfall and have warm temperatures much of the year [34].

Although acidification is a ongoing natural process in many soil environments, agricultural practices and pollution, mining, and other human activities have accelerated the process [36, 37, 38]. Most Ethiopian highland's soils turned to acidic due to high rainfall and intensive cultivation for long period of time. Highly weathered soils are usually acidic in reaction, low in essential nutrients and organic matter [23, 39]. Moreover, continuous use of acid-forming N fertilizers on highly weathered soils can aggravate acidity problem [40].

Soil acidity produces a number of specific constraints to plant growth. These include elemental toxicities (Al, Mn), reduced availability of nutrients, and reduced rates of certain biological processes and reduced access to soil water. Aluminum toxicity to plants is the main concern farmers with acid soils in Ethiopian highlands [41]. On the other hand, phosphorus ions are adsorbed more strongly on sesquioxide surfaces at lower soil pH due to, in part, the increasing positive charge on these colloids as soil pH decreases [34].



Source: Schlede, 1989

Figure 2. *Distribution acidic soils in Ethiopia and Eritrea.*

3. Sustainable Soil Fertility Improvement

Ethiopia, an agrarian country whose population and economy are highly dependent on agriculture, requires to seek ways and means to improve and sustain productivity of its farmland soils through adoption of integrated soil fertility management practices on a continuous basis with the full participation of farmers [42]. To feed the large and growing population, agricultural production has to be increased by improving the agricultural productivity per land area because most of accessible fertile lands have been cultivated [15]. Ethiopia faces a wider set of soil fertility issues beyond chemical fertilizer use, which has historically been the major focus for extension workers, researchers, policymakers, and donors. If left unchecked, this wider set of issues will limit future output and growth in agriculture across the country; in some areas limit the effectiveness of chemical fertilizer [23].

Integrated plant nutrient management method is need when seeking alternative nutrient management system in subsistence farming for social and economical acceptability [43]. Fertilization through organic and inorganic sources improves soil fertility of nutrient depleted soils as a result crop production increased. As per [22] report indicated that integrated use of 45 kg/ha TSP and 15 kg/ha Tithonia gave maximum maize grain yield in Kenya. On the other hand, liming is the most effective practice for reducing soil acidity problem [37]. Application of lime provided synergistic effect to TSP and *Tithonia* while slight grain yield increment obtained when TSP combined with lime since P is more limiting than acidity per se while an application of *Tithonia* and lime led increase grain yield by 15 times [22] (it has also shown on Figure 3).

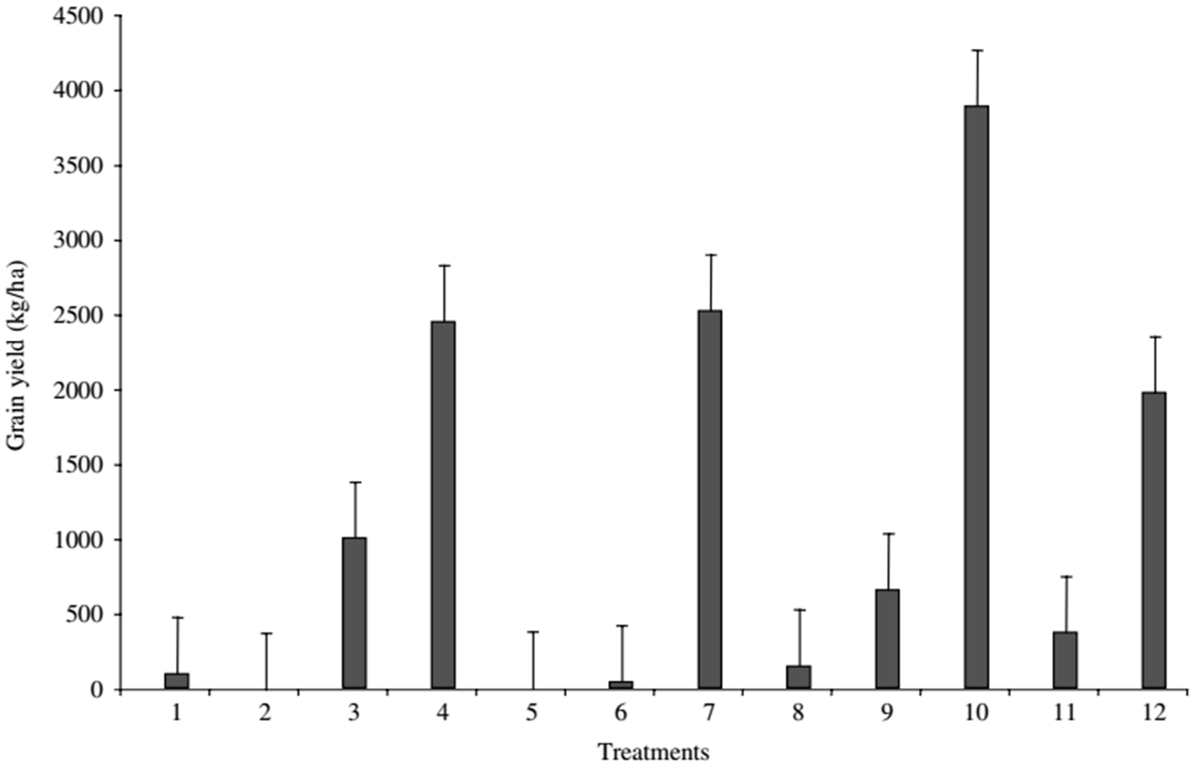


Figure 3. *Combine use effect of lime, green manure and P fertilizer on maize grain yield.*

Whereas: Treatment 1-control; 2, 4 t/ha lime; 3, Minjingu rock phosphate 60 kg/ha; 4, 60kg/ha TSP; 5, 15 kg/ha Tithonia; 6, 4t/ha lime+ 60 kg/ha rock phosphate; 7, 4t/ha lime+ 60 kg/ha TSP; 8, 4t/ha lime+ 15 kg/ha Tithonia; 9, 45 kg/ha rock phosphate+ 15 kg/ha Tithonia; 10, 45 kg/ha TSP+15 kg/ha Tithonia; 11, 4t/ha lime+ 60 kg/ha rock phosphate+15 kg/ha Tithonia; 12,45 kg/ha TSP+ 15 kg/ha Tithonia+4t/ha lime
Source: Source Tabu*et al.,* 2007

The integrated use of 32 kg/ha N, 10 kg/ha P and 8 t/ha farmyard produce 3- 3.44 wheat yield (>30% more yield over the control) on medium and low fertile soils of Dila and Dimile [44]. As per [45] study revealed that soil acidity problem can be partly improved by the application of only lime, wheat crop production cannot be improved appreciably without its combined application with NP fertilizers. As in [46] indicated that the combined use of 2 t/ha lime, 40 kg/ha N and 60 kg/ha P_2O_5 fertilizer showed significant effects on teff yield (Table 1).

As per [47] study disclosed that application of wood ash and manure has significant effect on the properties of acidic soils. In the same study resource soil that received the highest levels of wood ash (11.2 tons $CaCO_3$ ha^{-1}) showed increment in plant height by 41%, fresh shoot biomass by 100% and dry root biomass by 83%, respectively, compared to the control treatment (Table 2). However, maximum teff grain yield (3.13 t ha^{-1}) was found with combined application of 12 t ha^{-1} biochar and 100% recommended chemical fertilizer (40/60 N/ P_2O_5 kg ha^{-1}) and followed by 2.88 t ha^{-1} grain yield by using combined 2 t ha^{-1} lime and 100% recommended chemical fertilizer [46].

***Table 1.** Combined application of soil ameliorates and chemical fertilizer on tef yield.*

Amendments	Fertilizer Rate N/P_2O_5 (kg ha^{-1})	Grain yield (t ha^{-1})	Dry biomass yield (t ha^{-1})
No Amend	0	0.817^{h}	9.22^{f}
	20/30	1.623^{gf}	11.54^{def}
	40/60	1.870^{ef}	13.89^{cde}
4 t ha^{-1} Biochar	0	0.959^{h}	9.37^{f}
	20/30	1.860^{f}	14.33^{cd}
	40/60	2.354^{cde}	15.76^{bc}
8 t ha^{-1} Biochar	0	1.266^{gh}	10.40^{ef}
	20/30	1.999^{def}	13.59^{cde}
	40/60	2.676^{abc}	17.03^{bc}
12 t ha^{-1} Biochar	0	2.413^{bcd}	16.15^{bc}
	20/30	2.462^{bcd}	16.14^{bc}
	40/60	3.129^{a}	21.04^{a}
2 t ha^{-1} Lime	0	2.182^{cde}	13.36^{cde}
	20/30	2.296^{cde}	13.59^{cde}
	40/60	2.877^{ab}	18.16^{ab}
Probability (0.05)		**	**
CV		12.87	12.35

Source: Anteneh et al., 2015

***Table 2.** Effects of application of lime and wood ashon chemical properties of acidic soils.*

Treatment	Rate	pH	Ex. Ac	Ex. Al	CEC	Olsen P	PAls
			---------------- (cmol$_c$ kg^{-1})----------------			(mg kg^{-1})	(%)
Control	-	4.89^{i}	2.22^{a}	1.28^{a}	25.7^{a}	7.0^{p}	5.0^{a}
Lime (tons $CaCO_3$ ha^{-1})	3.5	5.15^{f}	0.85^{f}	0.13^{e}	25.8^{a}	7.4^{op}	0.5^{e}
	7.0	5.43^{e}	0.35^{h}	0.09^{e}	26.1^{a}	7.7^{no}	0.3^{e}
	9.2	5.63^{bcd}	0.23^{jkl}	0.07^{e}	26.4^{a}	8.1^{n}	0.3^{e}
	11.2	6.03^{a}	0.14^{no}	0.07^{e}	26.4^{a}	8.7^{m}	0.3^{e}
Wood ash (tons $CaCO_3$ ha^{-1})	3.5	5.16^{fg}	0.78^{g}	0.12^{e}	25.9^{a}	9.6^{kl}	0.5e
	7.0	5.42^{e}	0.35^{h}	0.10^{e}	26.1^{a}	10.5^{j}	0.4^{e}
	9.2	5.66^{bc}	0.19^{k-o}	0.08^{e}	26.2^{a}	12.2^{fgh}	0.3^{e}
	11.2	5.93^{a}	0.16^{mno}	0.06^{e}	26.3^{a}	13.8^{d}	0.2^{e}
Mineral P (kg ha^{-1}) plus lime (7 tons $CaCO_3$ ha^{-1})	32.5	5.58^{cd}	0.27^{ij}	0.09e	25.8^{a}	9.0^{m}	0.3^{e}
	65	5.67^{bc}	0.23^{j-m}	0.08^{e}	25.7^{a}	10.1^{jk}	0.3^{e}
	130	5.61^{bcd}	0.22^{j-m}	0.09^{e}	25.8^{a}	13.1^{e}	0.3^{e}
Manure P (kg ha^{-1}) plus lime (7 tons $CaCO_3$ ha^{-1})	32.5	5.57^{cd}	0.31^{hi}	0.09^{e}	26.4^{a}	8.9^{m}	0.3^{e}
	65	5.64^{bcd}	0.20^{i-n}	0.10^{e}	26.7^{a}	9.7^{kl}	0.4^{e}
	130	5.71^{b}	0.12^{o}	0.09^{e}	26.5^{a}	11.6^{hi}	0.3^{e}
Manure P (kg ha^{-1}) plus wood ash (7 tons $CaCO_3$ ha^{-1})	32.5	5.62^{bcd}	0.32^{hi}	0.07^{e}	25.7^{a}	12.5^{f}	0.3^{e}
	65	5.64^{bcd}	0.20^{jkl}	0.09^{e}	25.8^{a}	14.4^{c}	0.3^{e}
	130	5.62^{bcd}	0.16^{l-o}	0.07^{e}	26.4^{a}	15.6^{b}	0.3^{e}

Source: Asmare *et al*., 2015

Moreover, combining use of 5 t/ha manure and 2.2 t/ha lime in northwestern Ethiopian highlands gave maximum bread wheat grain yield (2.7 t/ha) it was 1.98 t /ha more yield over the control treatment [48] (it is located on Table 3).

***Table 3.** Interaction effect of rate of manure and lime on bread wheat grain yield.*

Manure (t ha^{-1})	Lime tha^{-1}		
	0	2.2	3.3
0	0.898^{c}	1.98^{b}	1.787^{b}
5	1.741^{b}	2.689^{a}	2.169^{b}
10	2.215^{b}	2.736^{a}	2.212^{bc}
* Lime and P	1.618^{C}	2.468^{A}	2.056^{B}

Source: Mekonnen *et al*., 2014

4. Conclusion

Soil nutrient depletion and acidity is the major problem to increase crop production in Ethiopian highlands in area where characterized by subsistence farming system. Integrated nutrient management is the most profitable and achievable method on small-scale holding farming system due to social and economical reasons. Integrated use of lime, chemical and organic fertilizers increased crop yield in Ethiopia highlands, most study findings revealed that combined use of 2-3 t/ha lime, 30-40 kg/ha N and 10-30 kg/ha P chemical fertilizer or 5-8 t/ha manure application improve crop yield in the area. On the other hand, some studies disclosed that lime rate can be substituted by 12 t/ha biochar or 11.2 t/ha wood ash to ameliorate the problem of acidic soils which is an alternative option for resource poor farmers.

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