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Nature Based Climate Change Adaptation Measures for Sustainable Crops Production in Ethiopia: Review

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Abstract

Ethiopian crop production system is tremendously exposed to climate change impacts. Climate change, the higher increase in growing season temperatures combined with high inter-annual and intra-seasonal variability of rainfall, is threatening the yield of agricultural crops like maize, teff, wheat, barley, fava bean, and sorghum in Ethiopia. This is because climate change leads to shortening of the maturity period, drought, diseases and pests, and dwindling of soil fertility. Therefore, this paper reviews the nature-based climate change adaptation strategies employed in the crop production system of Ethiopia in relation to balancing temperature, Co2, soil moisture, and nitrogen. This review shows that both nature-based and non-nature-based adaptation measures are practiced by Ethiopian smallholder farmers. Inorganic fertilizer application, use of improved varieties, planting date adjustment, agroforestry, and soil and water management, particularly soil and water conservation structures and irrigation are practiced to adapt climate change in crop production system in different parts of Ethiopia. Nevertheless, the application of conservation agriculture and organic fertilizer is used in limited parts of Ethiopia. Nature-based climate change adaptation measures such as CA, parkland agroforestry practices, soil and water management, and organic fertilizers enhance sustainable crop productivity through ameliorating temperature, conserving soil moisture, and increasing essential soil nutrients sustainably. Non-nature-based climate change adaptation measures like the use of inorganic fertilizers may maintain or increase crop productivity for a single growing season. Smallholder farmers should be encouraged to apply nature-based solutions of climate change adaptation measures for sustainable crop productivity. Further research is required to understand the response of crop yield production to the projected climate change under different adaptation measures.

Keywords

Nature based, Crop, Productivity, Sustainability, Adaptation

Introduction

Climate change is an existing phenomenon that pose a serious danger to agricultural productivity and ecological protection in Sub-Saharan Africa [1]. Ethiopia is tremendously exposed to climate change impacts, i.e., extensive periods of drought have become more frequent in the pastdecade and caused significant economic losses mainly through their impact on agricultural productivity [2]. Among the agriculture sector, crop production is the most vulnerable one to climate change [3]. Climate change in combination with other factors such as small land size, lack of resources, and increasing degradation of soil quality are the constraints that Ethiopia's farm systems are facing today and hamper sustainable crop production and food security [4].

It is predicted that crop grain yields are very sensitive to changes in CO_2, temperature, and nitrogen (N) fertilizer amounts [5-7]. For instance, [8] found that the wheat yield reduction (36 to 40%) than maize in the mid of the century (2021-2050).Similarly, [9] found that elevated temperature will reduce the total wheat production at a rate of 0.3928 Mt yr -1 during the period 1980-2016. Whereas, elevated CO_2 levels, water availability through irrigation, and nitrogen fertilizers have led to an increase in annual wheat production at 0.67, 0.25, and 0.26 Mt yr -1 , respectively, averaged over the period 1980-2016 in the case of India [9]. A strong increase in vulnerability is noted over time in the eastern and southern parts of Ethiopia [10]. The vulnerability analysis done for East Hararghe, Ethiopia, also revealed that more households are to be food insecure in the future than present [11].

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On top of this, climate change will cause losses of 31.1 percent agricultural GDP at factor cost by 2050 and climate change impacts tend to hurt the income of the poor in drought-prone regions among rural residents [12]. Thus, the use of different robust adaptation strategies in agricultural crop production is vital to halt yield reduction and food insecurity problems and further economic crises that caused due to climate change [12,13]. Ref. [14] also noted that frustration of smallholder farmers of Sub-Saharan Africa in crop production and hence food security due to the impact of climate change will continue unless vigorous adaptation measures are taken. Since temperature, CO_2, soil moisture, and nitrogen deposition are the parameters that changed due to climate change [15], implementation of nature-based adaptation measures is highly demanded in the agricultural sector. In which nature-based climate change adaptation measure is an ecological approach that aims to give an environmentally and socio-economically friendly solutions for environmental problems. However, what adaptation measures are practiced by smallholder farmers in Ethiopia to ensure sustainable agricultural crop production in the face of climate change has not been explored and reported in detail. Therefore, in this review, the climate change adaptation strategies employed for crop production in the agricultural sector of Ethiopia are evaluated in relation to balancing temperature, $CO_{2,}$ soil moisture, and nitrogen.

Climate Change and Its impact on Sustainable Agricultural Crop Yield Production in the Case of Ethiopia

Earth's average surface air temperature has increased by about 1°C since 1900, with more than half of the increase occurring since the mid-1970s [16]. Likewise, [17] shows that increasing temperature and decreasing rainfall amount, increasing unpredictability, and fluctuation of rainfall in Amhara Region, Ethiopia. According to [18], the trend of average annual temperature and rainfall has increased by about 0.72°C and 153.73 mm, respectively, from 1987-2017 in the case of Siyadebrina Wayu District, Ethiopia. [19] also noted an increasing minimum and maximum temperature and decreasing and variable annual and spring season rainfall in North Shewa zone, Ethiopia. The Rib watershed, north-western highland, Ethiopia, will continue to experience climate change with mean annual temperature increasing by 0.24°C per decade and an increase in annual and Kiremt rainfall and a decrease in Belg rainfall [20]. Moreover, simulations of future climate change impacts with the Hi-sAFe agroforestry model indicates that heat, drought, and nitrogen stresses increased about twofold from Past (1951-1990) to the future (2031-2070) in the case of Mediterranean Environment [21].

Consequently, [22] indicate that increased in carbon dioxide emissions and annual temperature, and decreasing annual rainfall negatively affect agricultural output growth in Ethiopia. Similarly, [23] show that increased CO_2 emissions negatively affect crop productivity of teff, maize, wheat, traded (coffee, oilseeds and pulses) and non-traded crops. [24] also indicate that increased rainfall has a positive impact on agricultural output, however increased average temperatures have a negative impact on agricultural output in Ethiopia. Projected impact of climate change (2041-2070) indicated that mean yields of tropical cereals decrease over 23% of tropical cereal harvested areas, while a decline in mean maize yield computed over 85% of harvested maize areas in West Africa, 32% in East Africa, and 29% in Southern Africa [14].

In Ethiopia, According to [25], maize yields will decrease by up to 43 and 24% at Bako and Melkassa stations, respectively, while simulated maize yield in Hawassa shows an increase by 51% at the end of the century (2099). [26] also predicted that more than 30% and up to 50% maize yield lose in the case of rainfed and irrigation agriculture, respectively, until the end of the century due to the strong heat response in Gambella Region, Ethiopia. Production of teff, maize, and sorghum will decline by 25.4, 21.8, and 25.2 percent, respectively, by 2050 compared to the base period in Ethiopia [12]. However, [27] found that climate change will probably have only relatively small effects on the average yields of maize, wheat, and sorghum in Ethiopia in 2035 and even in 2055. [28] illustrate that Ethiopian Nile Basins are negatively affected by climate change at varying levels. The higher increase in growing season temperatures combined with high inter-annual and intra-seasonal variability of rainfall adversely affect crop production [20]. For example, a very high crop yield decline was found in Denbia woreda of Amhara Region, Northwest Ethiopia since the past 20 years [29]. Similarly, [30] shows an adverse effect of climate change on agricultural crop productivity and production through shortening of maturity period, decreasing crop yields, depressing the quality and quantity of crops in Mettu Woreda, Ethiopia. Furthermore, climate change will force species to shift and induce an increase in coffee and tef yields by 31% and 8.3%, respectively, at high altitudes in the years 2041-2060 compared to 1988-2018 [31]. Whereas climate change will reduce coffee yield by 3% at low altitudes, and barley, maize, and wheat yield by 22.7%, 48%, and 10%, respectively, at high altitudes in Ethiopia [31].

Moreover, climate change is discarding crop production in Kolla (90 %), mainly maize and teff and Weynadega (79 %) such as fava bean, barley, and wheat crops in the case of Semien Shewa Zone of Ethiopia [32]. As a result, crop failure/ yield reduction is used as one of an indicator of climate change by small holder farmers of the Central Rift Valley of Ethiopia (31%) [33], Northwestern Ethiopia (24.8%) [34], and Eastern Ethiopia (37.36%) [17]. Similarly, the maize producers of Eastern Ethiopia smallholder farmers perceived that drought, diseases and pests, dwindling of soil fertility, and declining crop yields are the major impacts of climate change that affect maize production [17].

Strategies of Sustainable Agricultural Crop Yield Production in the Face of Climate Change in the Case of Ethiopia

There is a highly need to implement climate change adaptation measures to maintain and/or increase crop productivity sustainably in Ethiopia in the face of climate change [35]. The adaptation methods used in the agriculture sector include the use of improved crop varieties, application of inorganic fertilizers, conservation agriculture, soil and water Management (in situ water harvesting measures, soil and water conservation measures, and supplementary irrigation), agroforestry, adjusted sowing dates, and application of organic fertilizers (see Table 1) [18,19,29,33,36,37]. From these practices, the use of improved crop varieties, conservation agriculture, soil and water Management (in situ water harvesting measures, soil and water conservation measures, and supplementary irrigation), agroforestry, adjusted sowing dates, and application of organic fertilizers are nature-based climate change adaptation measures. Where the International Union for the Conservation of nature (IUCN) defines nature-based solutions as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits [38]." For instance, from improved varieties, haricot bean (Phaseolus vulgaris L.) and early and mid-maturing maize (Zea mays L.) varieties, as well as agricultural practices like row-sowing, band fertilizer application, intercropping, and traditional rainwater-harvesting are continuously practiced by the farmers [39]. These continuing technologies have a high potential for reducing the vulnerability of rain-fed agriculture to rainfall variability in the case of the Central Rift Valley of Ethiopia [39]. Furthermore, water harvesting represents one of the most important strategies of coping with water shortage in arid and semi-arid regions [40]. Similarly, [11] indicate that smallholders of East Hararghe, Ethiopia, employee climate change adaptation strategies such as soil and water conservation measures and adjusting sowing dates are food secure than non-users. Besides, [33] also show that crop diversification, sowing date adjustment, soil and water conservation and management, increasing the intensity of input use like fertilizers and pesticides, integrating crops with livestock, and tree planting are the efforts made by smallholder farmers of the Central Rift Valley of Ethiopia to adapt climate variability and change.

Adjusting the sowing date to minimize the impact of heat stress, as well as using late-maturing cultivars and new varieties are more effective and primarily required under future climate conditions for the Gambella region [26]. Adoption of crop diversification has a positive and significant effects on farm income and improves the well-being of farm households and build a resilient agricultural system in the Nile basin of Ethiopia [41]. Improved seed, urea, compost and increased summer rainfall are significantly associated with the possibility of increasing maize yield [42]. However, the priority choice of climate change adaptation measures varies per agroecology of the area.

For example, changing sowing date (30.8 %) followed by fertilizer application(21.4%) and crop diversification (19%) used in lowland area, while terracing (57.5 %) followed by changing sowing date (11%), crop diversification (7.8 %) and income diversification (7.6 %) used in high land areas Northern Ethiopia [36]. According to this review, inorganic fertilizer application, use of improved varieties, planting date adjustment, Agroforestry, and soil and water management, particularly soil and water conservation structures and irrigation are widely practiced to adapt climate change in crop production system in different parts of Ethiopia. However, the application of conservation agriculture and organic fertilizer is used in limited parts of Ethiopia (see Table 1).

Conservation agriculture

Conservation agriculture (CA) like intercropping and crop rotation practices could be the best promising technologies that would improve sustainable production and soil improvement [43]. CA together with drip irrigation is also an efficient water saving technology and has substantial potential to sustain and intensify crop production in the Sub-Saharan Africa region [44]. CA with drip irrigation is proved to be an efficient water-saving technology while improving soil properties to support sustainable intensification in the Sub-Humid Ethiopian Highlands [45]. CA-based systems have the potential to improve crop productivity through improved soil health [46]. For instance, improved fallow using *Tephrosia vogelii* and *Cajanus cajan* legume species significantly increased soil pH, organic carbon, and total nitrogen levels compared with the natural fallow in Southwestern Ethiopia. Hence, for Maize, grain the yield increased by 80% for *Tephrosia* and 41% for *Cajanus* compared with the traditional fallow [47]. According to [48] reduced tillage is implemented by smallholder farmers in Kembata, Tembaro Zone, Southern Nations, Nationalities, and Peoples' Region of Ethiopia as climate change adaptation and mitigation measures.

Parkland Agroforestry system and practice

Agroforestry systems are resilient to climate change [49] as well as woody plant species of Agroforestry systems and their functional traits are essential to ensure sustainable soil management [50]. Agroforestry systems could reduce maize yield losses where climate change threatens maize productivity in Ethiopia [51]. For instance, [21] indicate 20-35% reduced climate change impacts like heat, drought, and nitrogen stresses in an agroforestry systems with medium-sized trees otherwise which would be increased about twofold from past to future. Parkland agroforestry has mutual benefits on providing food security to small-scale farmers and improving the climate change adaptation and mitigation strategies in the case of Tigray Region, Ethiopia [52].

Farmers with increased number of trees on their farm land have increased crop production in the face of climate change in Tigray, Northern Ethiopia [53]. Reductions in the yields of major crops were noticed in the Parkland Agroforests of Southwestern Niger due to the *Faidherbia albida (Delile)* tree dieback in the system [54]. Positive effect of agroforestry in combination with enhanced manure management is found as a climate smart strategy in Central Rift Valley, Ethiopia [15]. [55] found that parkland agroforestry practices can be used as an environmentally friendly and sustainable alternative to maintain soil fertility. Increased soil nutrients and moisture was found under Agroforestry system of *Rhamnus prinoide* intercropped in the wheat fields than agricultural farm land in the Drylands of North Ethiopia [56].

Table 1: Adopted climate change adaptation strategies in the crop production system of Ethiopia.

No	Adaptation practices	Adoption level in %	Study area	Adoption level in %	Study area	Adoption level in %	Study area	Adoption level in %	Study area	Adoption level in %	Study area	Adoption level in %	Study area	Number of study area practiced adaptation measures	References
1	Inorganic fertilizer														
	Fertilizer Application and techniques	89.4	Siyadebrina Wayu District, Ethiopia	40	Eastern highlands of Ethiopia		South Omo and Segen Area People's Zones of Southwest Ethiopia		Basona Worena District, North Shewa zone, Ethiopia	14.3	district, Northern Ethiopia	14	Arsi Negelle district of West Arsi Zone,Oromia, Ethiopia	4	[17,18,33,36]
2	Improved varieties														
	Improved crop varieties/ Change of crop varieties	75.3		50		33.95		93.6						4	[17-19,37]
	Pest resistance, high yielding, and drought and heat tolerant crops	77.5												1	[18]
	use of early maturing crop					27.03								1	[37]
3	Conservation Agriculture														
	Crop rotation or intercropping with cereals and legumes	71.7		80										2	[17,18]
	Conservation tillage	25.5												1	[18]
	Crop residue management	41.1												1	[18]
4	Organic fertilizer														
	Compost and manure management	27.7												1	[18]

5	Soil and water management														
	Mulching	13.1												1	[18]
	Water management	8.4												1	[18]
	Water harvesting	9.5												1	[18]
	Supplementary Irrigation			10				85.1				3		3	[17,19,33]
	Soil and Water Conservation (terracing)			65		66.21		80.9		36.7		11		5	[19, 29,33,36,37]
6	Agroforestry														
	Agroforestry	32.9				35.13		34.0				16		4	[18,19,33,37]
	Crop and livestock integration											8		1	[33]
7	Planting date adjustment			>90		42.56				18.4		10		4	[17,33,36,37]
8	Other														
	Crop diversification											23		1	[33]
	Post-harvest technology practices	58.7												1	[18]

Similarly, [57] indicated that higher soil moisture content at outer tree canopy cover area of *Albizia saman* (9 m distance) than in the open area (non-canopy cover) in the maize fields in the case of Annamalai Nagar, Tamil Nadu, India. Consequently, significantly higher LAI, biological yield and grain yield of maize were noticed under the canopy of *A. saman* from 3 m to up to 9 m distance apart the trunk of *A. saman*. In *Populus deltoides* based agroforestry system, the higher moisture content is found in 5 × 4 m spacing at a soil depth of 15-30 cm [58]. Ref. [59] also found that in the alley cropping system, woody vegetation helped to preserve soil moisture in the upper 20-30 cm layer by reducing the drying effect of wind and direct sunlight. This system is also showing a favorable range of temperature for productivity than in the monoculture. Hence, the alley cropping system can be particularly favorable for shallow-rooted intercrops, by controlling the water and heat balance of the soil and by moderating harmful extremities such as drought, extreme cold or heat.

In-situ Rain Water harvesting structures (IRWHS)

On farmland in-situ rain water harvesting is a stoppage of net runoff from a given cropped area by holding rain water and prolonging the time for infiltration [60]. Land suitability analysis indicates that a large part of the upper Blue Nile basin is suitable for in situ and ex situ water harvesting systems, which implies scaling of water harvesting practices for building resilience against climatic shocks [61]. More than half of the watersheds of the Jemma subbasin are also highly and optimally suitable for in-situ water harvesting under baseline and future climate scenarios [62]. Regarding to the success of IRWHS, a Targa in-situ moisture conservation structure has produced significantly higher grain yield, plant height, cob length, and biomass than Trus and Tied-ridge in Moisture Stress Areas of Mirab Abaya Woreda, Southern, Ethiopia [63].

Similarly, [64] found higher soil moisture, grain yield, and biomass in the Targa when compared with the control in the dry areas of Wolaita zone, southern Ethiopia. Ref. [65] Shows that the in-situ rainwater harvesting technique significantly increased the grain yield of maize due to the improved soil moisture storage in the case of Fedis District, Eastern Hararghe, Ethiopia (see Table 2). [66] have also indicated that pot holes, tied ridges, and mulching, in increasing order of effectiveness, have the potential to reduce the damage caused by drought stress to maize growth and grain yield by conserving moisture of the farm in drought-prone regions.

It is also projected that the association of zaï with mulch can increase crop yield depending on the climate projection scenario RCP 8.5, under which carbon dioxide (CO_2) concentrations are projected to reach 936 ppm by 2100 [67]. Long-term effect of in-situ soil moisture conservation measures on soil properties in Emblica officinalis based agroforestry system showed significant improvements in water holding capacity, porosity,

Table 2: The role of in-situ rain water harvesting structures on agricultural crop yield improvement.

No	In-situ rain water harvesting structures	Crop type	GY (kgha^{-1})	DMB (kgha^{-1})	Ph(cm)	CL (cm	100swt (gm)	Study area	References
1.	Targa	Maize	7150a	8230a	208a	39.36a	-	Abela Sippa kebele Wolaita zone, Ethiopia	[64]
	Tie-ridge		6190a	780ab	202a	35.26b	-		
	Zai		4500b	5760c	201a	37.30ab	-		
	Control		4900b	6150bc	196a	35.50b	-		
2.	Trus	Maize	5784.0bc	7386.7b	178.650c	23.63b	33.03a	Mirab Abaya Woreda, Southern, Ethiopia	[63]
	Targa		8843.0a	9922.1a	208.283a	29.40a	35.38a		
	Tie-ridge		6250.9b	6958.8b	200.45ab	24.53b	35.01a		
	Control		4525.6c	6361.6b	184.667bc	24.53b	34.89a		
3.	Tied Ridge	Maize	5203a	-	-	-	-	Fedis District, Eastern Hararghe, Ethiopia	[65]
	Contour Ridge		4779a	-	-	-	-		
	Furrow Ridge		4404ab	-	-	-	-		
	flatbed planting/Control		3635b	-	-	-	-		
	Tied Ridge	Maize (Zea mays L.)	9,941					Dugda District, East Shewa zone of Oromia Region, Ethiopia	[78]
	Furrow closed at both ends		8674						

organic carbon content, cation exchange capacity, available N, available K, microbial biomass carbon, potential nitrogen mineralization and dehydrogenase activity of the soil than control [68].

Application of Organic fertilizer vs Inorganic Fertilizer

Appropriate application of nitrogen fertilization would improve part of the projected impact of climate change on agricultural crop yield [8]. Soil fertilized with 100% recommended NPK combined with farm yard manure produced the superior growth of plants and the highest amount of total fruit yields [69]. Moreover, organic fertilizer can help to shape the microbial composition and recruit beneficial bacteria into the rhizosphere of the plant, leading to improved plant quality and reduced heavy metal content in rhizosphere soil and plant leaves [70]. There are robust simulated interactions between climate change factors and nitrogen fertilization and indicates that maize intensively managed with more nitrogen fertilizer will be more sensitive to climate change, pointing the importance of balanced nutrient application [71]. Conservation agriculture (CA) with drip irrigation is an efficient strategy to improve crop production while enhancing soil quality as it improves total carbon and nitrogen than traditional conventional tillage in Sub- Saharan Africa [72]. Biochar, when applied to soils is reported to enhance soil carbon sequestration and provide other soil productivity benefits such as reduction of bulk density, enhancement of water-holding capacity and nutrient retention, stabilization of soil organic matter, improvement of microbial activities, and heavy metal sequestration. Furthermore, biochar application could enhance phosphorus availability in highly weathered tropical soils [73]. [74] also revealed that biochar significantly increases soil C, exchangeable K^+ contents, field capacity, and available water content in the case of South Sudan.

A 22-years field experiment has indicated that organic matter amendments can mitigate the negative and exploit the positive effects of climate change on crop production by enhancing soil quality [75]. Similarly, [76] found that organic fertilizer has the highest yield resilience in response to regional relative humidity changes compared to integrated and chemical fertilizers since specific soil microbes have the potential to help crops face environmental vulnerability in subtropical regions. [77] indicate that manure amendment could alleviate the negative influences of future climate change on crop growth and nitrogen utilization under the predicted climate change scenario by 2100. [48] shows that application of manure in the soil is implemented by smallholder farmers in Kembata Tembaro Zone, Southern Nations, Nationalities, and Peoples' Region of Ethiopia as climate change mitigation measures.

Conclusions and Recommendations

Nature-based climate change adaptation measures enhance sustainable crop productivity through ameliorating temperature, conserving soil moisture and increasing essential soil nutrients. Conservation agriculture increases grain yield by improving soil health. **Parkland Agroforestry system mitigates and adapt to climate change as it is able to sequester CO_2 via the woody plants and soil of its system. This system can combat yield reduction due to climate change by improving soil nutrients, conserving soil moisture, and ameliorating temperature of the area.** On farmland in-situ rain water harvesting structures such as Targa and Tied Ridges are climate change adaptation strategies that combat maize grain yield reduction in moisture stressed areas. **The crop production system managed with organic fertilizer than inorganic one is** resilient and productive in response to climate change as it is supported by the beneficial soil biota. Sustainable crop production systems under climate change should be supported with nature-based adaptation measures than non-nature-based measures. Based on this review, the following are recommended to researchers to undertake further investigation and policy makers to design agricultural policies that urge and force the implementation of nature-based climate change adaptation measures that enable the crop production system to be productive and sustainable.

For researchers:

- Long term field experiment on the response of crop yield productivity using organic versus inorganic fertilizers in response to climate change is highly essential in Ethiopia.
- The response of crop yield productivity other than maize using different in-situ rain water harvesting structure should be evaluated.
- For policy makers:
- A robust policy should be developed that strengthens/ enforce the practice of nature-based adaptation measures in crop production systems of Ethiopia to ensure sustainability.
- Extension works on organic fertilizer practice such as biochar, compost, and vermicompost should be encouraged.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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