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Effect of Climate Change on Soil Productivity in Developing Countries

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Authors' contributions

This work was carried out in collaboration between both authors. Author AOF wrote the first draft of the manuscript. Author UKS managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Climatic change may occur due to high greenhouse gas emissions arising from dependence on solid fuel which triggers frequent environmental disasters such as extreme heat, droughts, floods, cyclones in many developing countries. Agriculture is sensitive to climate change in developing countries because they are mostly dependent on rainfall to meet crop water requirements. The objective of this paper is to review current literature on the impacts of climate variability on soil productivity in developing countries in order to improve crop production, ensure food security and economic development. There are numerous reports on adaptation to climate change but studies on estimation of greenhouse gas emissions from agricultural settings are either missing or scarce in developing countries. Soil organic matter has been identified as the most important factor that affects the productivity of the soil and determines crop yields. However, extreme heat can cause a decline in soil productivity by increasing soil organic matter decomposition and decreasing soil available water. Lower available water has led to the use of wastewater or sewage for irrigation which can cause soil pollution. There are also reports of increasing water logging and nutrient losses via leaching and run off under flooding conditions. Sea level rise has caused an increase in soil salinity of coastal areas with devastating effects such as total loss of rice fields. Sequestration of

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carbon in trees, soil and microorganisms are major mitigation strategies because carbon dioxide is the most abundant greenhouse gas. Various mitigation strategies for reducing methane and nitrous oxide emissions in rice fields are also discussed. Conservation agriculture and tillage may be used to increase infiltration, conserve soil water and preserve soil organic carbon under drought or extreme heat. Adoption of conservation agriculture and [minimum or no-] tillage will help reduce economic losses to the farmers and increase crop yield. The adaptation and mitigation of climate change in developing countries is limited by social, economic and political factors. Adoption of low emission strategies and enforcement of environmental laws by developing countries will help reduce the frequency and impact of extreme climatic events.

Keywords: Climate change; soil productivity; soil organic matter; developing countries; mitigation; carbon sequestration.

1. INTRODUCTION

Climate change depicts a change in long-term weather patterns with a shift towards higher temperatures and lower or extreme rainfall events [1]. Higher temperatures result in the phenomenon called global warming which is caused by human activities such as use of fossil fuels combustion and land use changes [2]. The combustion of coal and oil releases greenhouse gases which traps heat in the atmosphere [1]. Greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3) absorb infra red radiation which increases the temperature in the atmosphere [3]. Agricultural activities such as nitrogen (N) fertilization, use of animal manure and crop residues may also contribute to GHG emissions depending on farm management practices such as water-logging, open air burning and storage [4-5]. Conventional tillage of agricultural lands is a major source of CO_2 because it increases soil organic matter decomposition. Surface waters, cities and soils have also been reported as sources and sinks for GHGs [6-8].

Carbon dioxide is the most abundant GHG in the atmosphere with a global mean concentration close to 400 ppm [9]. The mean concentration of CO_2 increased from 280 to 397 ppm in 164 yrs resulting in rise in mean global temperature by 0.6 to 1°C in this period [10]. It has been estimated that average CO_2 concentration may rise to 570 ppm by the year 2100 causing an increase of about 1.9°C and 3.8 m in the global average temperature and mean sea level respectively [11]. Transportation, buildings, industry and electronics contribute to CO_2 emissions in urban environments [12] while GHG emissions from agriculture and land use amount to nearly 30% of the total emissions. GHG emissions especially CO_2 are on the rise in developing countries around the world due to urbanization and dependence on fossil fuels. Higher GHG emissions are probably responsible for the higher number of environmental disasters which occur with greater impacts in developing countries [13].

Developing countries have a low level of coping with the adverse effects of climate changes probably because of their economic status [14]. They are vulnerable to extreme climatic variability which causes socio-economic problems that hinder development [15]. Developing countries are facing problems caused by population growth, urbanization, and change in land use pattern [16]. Increasing population growth associated with many developing countries requires increasing food production [17].

Many developing countries practice subsistent farming and find it difficult to feed their growing population partly due to the effects of climate change [18]. Agriculture is sensitive to climate change in most developing countries because they practice rain fed arable cropping [19]. Increases in temperature and extreme rainfall events greatly impact the soil which is the medium for plant growth. It’s important to know how climate change has affected soil productivity because soil productivity plays a key role in agricultural development [20].There have been numerous papers reporting the effect of climate change on agriculture but there are few papers on the effect of climate change on soil productivity in developing countries. Hence this paper discusses 1) climate change in developing countries 2) soil productivity 3) effect of climate change on soil productivity in developing countries with case studies of selected countries and 4) strategies for mitigation of climate change.

2. CLIMATE CHANGE IN DEVELOPING COUNTRIES

Carbon dioxide is the most important GHG with a concentration that is about 300 times that of CH_4 and about 900 times of N_2O (Fig. 1). Emissions of GHGs such as CO_2, CH_4, and N_2O which have risen by 37.5%, 151%, 19.3% respectively between 1750 and 2008 has caused a global rise in temperature [21]. This has led to a warming climate worldwide due to increases in atmospheric temperature [22-23]. The global mean temperature has increased 0.74°C during the past century, and the warming has accelerated at 0.13°C per decade during recent 50 years [24].

It has been estimated that temperature, precipitation, days of heat waves and extreme precipitation intensity will increase at rates of 0.38°C per decade, 12.6 mm per decade, 6.4 d and 47 mm per decade in the 21st century respectively in China [25]. This is higher than expected change in developed regions such as European Alps where about 0.25°C warming per decade is expected until the mid of the 21st century and an accelerated 0.36°C warming per decade is expected in the second half of the century[26].

Global warming is responsible for changes in air temperature, relative humidity, and solar radiation which has affected the hydrological cycle [27]. Global warming is also responsible for the melting of ice in Polar Regions such as Arctic sea, Greenland and Antarctica resulting in the rise in sea level [28]. Global sea rose during the 20th century by 18 cm and is expected to rise by 0.28 m to 0.98 m by 2100 [29]. This is a threat to coastal areas and islands in developing countries/regions that are not well equipped to cope with the adverse effects of climate change.

Small-island developing states such as Mauritius are particularly vulnerable to climate change impacts due to higher mean temperature, extreme heat waves and cyclones, sea-level rise as well as flash-floods caused by an increase of 0.85°C in mean temperature above pre-industrial levels [30-31]. Sea surface temperature has also risen by 0.18°C per decade while the ocean temperature has risen by 0.11°C [29]. Climate change also causes ocean acidification due to high CO_2 in the air which dissolves in the water to form carbonic acid [32]. This is toxic to marine organisms and can lead to loss of biodiversity and mortality.

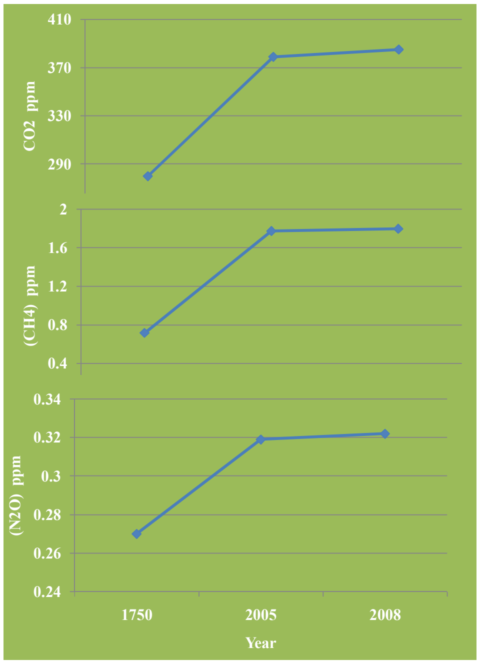

Fig. 1. Concentrations of greenhouse gases between 1750 and 2008 [CO_2-carbon dioxide; CH_4-methane; N_2O-nitrous oxide]

(Data source: Jat et al. 2016)

Information on climate change in developing countries is limited because of lack of documentation especially in Africa [33]. However, few studies have reported that climate variability has increased in West Africa with warming trends and frequent extreme rainfall events [34-36]. In developing countries, climate change is associated with droughts, monsoons, widespread flooding, wild fires, and rain-induced landslides. There have been reports of heat waves in India and Portugal, severe droughts in China, tropical cyclones in Bangladesh and unusually strong monsoons in Pakistan [37]. Bangladesh is affected by torrential rain, glacier melt, upstream water flow and tidal surges while Nepal is highly prone to hydrological risks including torrential rain, floods, glaciers resulting in erosion and landslides [38]. Bangladesh and Nepal are vulnerable to severe flooding due to the effect of sea level rise and glacier melts as a result of a warming climate.

These extreme climatic events create a spiral of debt burden on developing countries [39]. Economic losses due to climate change has been estimated to be about 7% GDP of developing countries in sub-Saharan Africa, small island developing states and South Asia [40]. The inevitability of climate change indicates the need for adaptation which increases resilience to risks [41]. Adaptation will prevent displacement of hundreds of millions of people in the East, Southeast, and South Asia that will be affected by coastal flooding by year 2100 [29].

The ability to adapt to a changing climate is dependent on economic status [42]. [43] analyzed the link between income and adaptation to climate events. They found strong evidence for an income based demand effect for adaptation to two climate-related extreme events; tropical cyclones and floods. They explained that adaptation productivity in high-income countries is enhanced because of better public services and stronger institutions. Agriculture is the sector most severely impacted by climate change. It has been reported that lack of access to credit is one of the main barriers for farmers to adapt to climate change in South Africa and Ethiopia [44].

Climate change results in poor and unprofitable yields, thereby making poor farmers more vulnerable, especially in Africa [45]. It has been predicted that crop yield in Africa may decrease by 10-20% by 2050 or even up to 50% due to climate change because African agriculture is predominantly rain-fed and strongly dependent on frequent extreme weather [46-47]. Estimated marginal impacts suggest that global warming is harmful for crop productivity while predictions from global circulation models confirm that global warming will have a substantial impact on net crop revenue in Kenya [48]. [49] reported that global warming has caused an economic loss of about $820 million to China′s corn and soybean sectors in the past decade and yields are projected to decline by 3–12% and 7–19%, respectively, by 2100.

The formation of GHGs such as ozone has been reported to reduce crop yields in India in the first decade of the 21st century. Wheat is the most affected crop with losses of 3.5 million tons (Mt), followed by rice at 2.1 Mt, with the losses mainly in central and north India. The nationally aggregated yield loss is sufficient to feed about 94 million people living below poverty line in India [50]. Scientists have reported that drought and extreme heat reduced crop yields by as much as 10% between 1964 and 2007 while extreme cold and floods did not result in a significant reduction in crop production. Crop production in North America, Europe and Australia experienced about 20% decline due to drought and extreme heat, compared to less than 10% in Africa and Latin America [51]. This was attributed to differences between agricultural methods and practices in these regions [51]. Sustainable soil use and increasing soil productivity may help alleviate and reduce economic losses due to extreme climatic variability in developing countries.

3. SOIL PRODUCTIVITY

Soil productivity has been defined as the ability of a soil to support plant growth without external inputs [52]. Increasing basic soil productivity can lead to a reduction of fertilizer application and high crop yield [53]. The productivity of a soil can be evaluated based on crop production in unfertilized soil within the agricultural ecosystem [52].The productivity of the soil can also be measured by physical properties such as soil structure, rate of water infiltration, water holding capacity and hydraulic conductivity; chemical properties such as organic matter content, cation exchange capacity, and pH; and biological properties such as fauna and flora activity in the soil. Results of a past study showed that the suitable parameters for soil productivity assessment were soil available water, soil pH, clay content, and organic matter content [54].

Duan X [55] reported that organic matter content and available water capacity impact long term soil productivity in China, whereas soil clay content and pH were less important. There is a general consensus that soil organic matter is the most important factor in soil productivity. [52] reported that soil organic matter is a better predictor of soil productivity because it correlated more strongly than other nutrients with crop yield. Several studies also confirmed that soil organic carbon (SOC), the basic unit of organic matter, played a greater role in increasing soil productivity than availability of N/P to food crops [56-57].

Even though the long-term applications of both organic and chemical fertilizers were capable of increasing soil productivity on the North China Plain, organic fertilizers were more effective than chemical fertilizers [52]. The positive response of crops to soil organic matter and organic fertilizers may be due to its potential to increase cation exchange capacity and water absorption capacity of the soil. This may explain why higher productivity soils exist in forest areas which are high in litter and rich in organic matter [20]. Conversion of forest land or grassland to dry farmland may seriously degrade soil productivity [20]. The main difference between forestland or grassland and farmland is tillage which reduces organic matter content of soils and increases GHG emissions. Tillage increases the rate of soil organic matter decomposition [58] by increasing soil aeration which provides more oxygen for the decomposition or oxidation of organic matter. Decomposition of organic matter produces carbon dioxide gas which is a major greenhouse gas.

It has been reported that complete removal of surface organic matter reduced nutrient availability which can affect plant nutrition and growth [59]. This is consistent with a previous study that showed that nutrient supply for biomass uptake was mainly from soil organic matter mineralization and mineral weathering [60]. The study also suggested that soil acidity may lead to a decline in long term soil productivity [60]. Another important soil factor is availability of water in the soil for plant growth. Soil productivity can be improved with an adequate input of water and nutrients [57]. Adequate water is needed to transport the nutrients through the soil to the plant and within the plant tissues. A previous study has reported that available soil water and soil water conductivity was positively correlated with crop yield [61]. Water availability is the main limitation for crop production in Mediterranean and semiarid areas, where soil moisture is below field capacity for nearly the entire growing season [62].

4. EFFECT OF CLIMATE CHANGE ON SOIL PRODUCTIVITY

Increase in temperature and evapotranspiration may affect crop water requirements (CWR). On an average, 1°C increase in temperature may increase the CWR by 2.9% which can lead to increased stress on groundwater resources [63]. Increased temperature may also lead to lower available water in the soil which indicates lower ability of the soil to supply water for crop growth. In order to meet increased CWR under drought, farmers practice some agricultural adjustments, such as application of irrigation water, to increase crop yield [64]. However, in cases where the soils are highly degraded with low water infiltration into the soil, irrigation may not be the solution.

Farmers are forced to irrigate (Fig. 2) farmlands with untreated wastewater or sewage due to water scarcity under drought conditions which has led to pollution of farmland soils and even the crops grown [65]. Heavy metal pollution of irrigated farmland soils was reported in Zambia, Morocco, Nigeria and Benin (Abdu, 2010; Koumolou et al., 2013; Kapungwe, 2013; Al-Jaboobi et al., 2014). This is mostly reported in developing countries because they do not have strict regulations about use of wastewater or domestic/industrial effluents on farmlands.

Despite the adverse effects of sewage irrigation, it has the capacity to supply nutrients and water, increase microbial activity and enzymatic activity. A past study found that long term use of sewage for irrigation led to a build-up of carbon (C), N and phosphorus (P) in soils [65]. It has also been reported that both salinity and sodicity declined under drip irrigation in China with dramatic increases in N, P, and potassium (K) concentrations in the soil [52]. This result is contrary to a study that reported that soil salinity was increased with the application of wastewater. They concluded that irrigation with wastewater, which is generally more sodic and saline than groundwater, increases the rate of soil sodification [66]. Drip irrigation may not make a difference in dry bare soils which have high evaporation and upward water flow which leads to surface accumulation of salts. This problem can be resolved by establishing plant cover which reduces evaporation from the soil surface. [67] has also shown that irrigation agriculture accelerates organic matter decomposition which will lead to lower soil productivity.

An increase in temperature may lead to rapid decomposition of organic matter and lower soil productivity [68]. Global warming accelerates soil organic matter decomposition (Fig. 2) due to increased microbial and enzymatic activity [69]. Climate change has caused a depletion of SOC in the Indian Himalayan Mountains in the past few decades due to the rise in mean minimum (by 1.6°C) and monthly temperature (by 1.3°C) and land use change [70]. Simulation results in China showed that SOC will generally decrease during the next decades. They predicted that upland soils will lose SOC by 2.7 t C/ha, 6.0 t C/ha, and 7.8 t C/ha at the 0–30 cm depth by the year 2020, 2050, and 2080, respectively, under the conventional tillage without organic material amendment [71].

On the contrary, increased precipitation may lead to increased SOC storage in the Indian Himalaya, unless soil erosion occurs during intense storms [72]. A previous study reported that surface soil organic matter concentration is negatively correlated with annual mean temperature and positively correlated with annual mean precipitation [73]. This indicates that a warming climate will reduce soil organic matter content and intense rainfall will increase soil carbon storage. Aerobic conditions facilitate organic matter decomposition while anaerobic conditions which prevail under flooding will reduce rate of organic matter decomposition in the soils. However, the frequent cycling between anaerobic and aerobic conditions of paddy-upland rotation resulted in a greater rate of soil organic matter decomposition in the Indo-Gangetic rice plains where rice and wheat are grown in rotation [74-75].

Climate variations such as frequent intense precipitation could also lead to nutrient losses from the soil due to leaching and run off which reduces nutrient available for crop growth. High nitrogen concentrations have been detected in groundwater and surface waters indicating N losses via leaching and run off 76]. Seasonal rainfall was responsible for 39 to 84% of the variability in N leaching (1970-2009) under maize in the North China Plain [77]. Other factors that could affect leaching losses are soil structure and tillage practices adopted on farmlands. Increased moisture will also lead to accelerated weathering of soil minerals [78] while climatic variability such as floods or droughts can cause soil degradation via processes such as water logging, salinization, and alkalinization [79]. It was found that the soil productivity index reflects the balance between soil degradation and resilience. A reduction in soil productivity index indicates that soil degradation processes overcame the soil resilience [79].

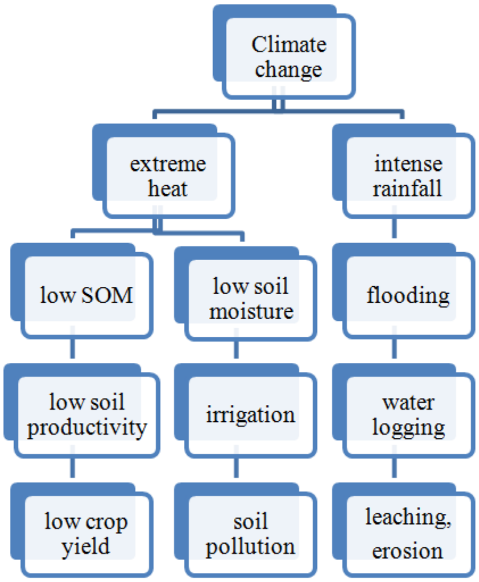

Fig. 2. Effect of climate change on soil productivity (SOM-soil organic matter)

Decline in soil productivity due to climate change is a major function of soil erosion and degradation. Soil erosion is a major environmental threat to agricultural production in many tropical and sub-tropical regions of the world [80]. Soil degradation by water erosion has been aggravated in the Peruvian Andes due to steep slopes, sparse vegetation cover, and sporadic but high intensity rainfall. Soil erosion risk in this region was associated with climate change [81]. Close links between climate change and soil erosion have been observed in the past decades because changes in temperature and precipitation affect infiltration rate, soil moisture, land use and crop management [82]. Soil erosion intensified by climate change and cattle grazing was catastrophic for three centuries (~ 1660–1960 AD) and was characterized by almost total loss of vegetation and underlying soil in the heathland ecosystem of Haukadalsheiði, south Iceland [83].

5. MITIGATION STRATEGIES

5.1 Reducing Greenhouse Gas Emissions

5.1.1 Carbon dioxide emissions

Reduction of CO_2 emissions is the main strategy in mitigation of climate change since the gas is majorly responsible for global warming [84]. There are a variety of methods used to remove CO_2 emitted from combustion of fossil fuel and other human activities. These methods are based on removing CO_2 from the atmosphere and storing it as carbon in the soil, plants or other suitable materials that can adsorb carbon (Fig. 3). Carbon dioxide capture and sequestration (CCS) is one of the methods used to reduce CO_2 emissions caused by fossil fuel combustion. CCS involves three step operations: capture of CO_2 emitted from land, industrial and energy-related sources before or after combustion, compressing and separating it, transport to a storage site and injecting it deep underground in secure geological formations [85].

Plantation forests have been reported to be the most effective and ecologically friendly way of removing CO_2 and increasing carbon sinks in terrestrial ecosystems [86]. It has been estimated that 1.686 Pg C was sequestered by plantations in China in 62 yrs and simulations have predicted that China's forestation activities will continue to sequester carbon to a level of 3.169 Pg C by 2050 [86]. The potential of Pará rubber, a perennial plantation, to remove CO_2 from the atmosphere was evaluated in Eastern Thailand. It was found that soil-water interaction resulted in the sequestration of 0.04 tons C/km^2/year while the amount of carbon stored in the Pará rubber plantation was 645 tons C/km^2/year. This suggests that Pará rubber tree plantations are more efficient in the removal of atmospheric CO_2 than soil water interactions [87].

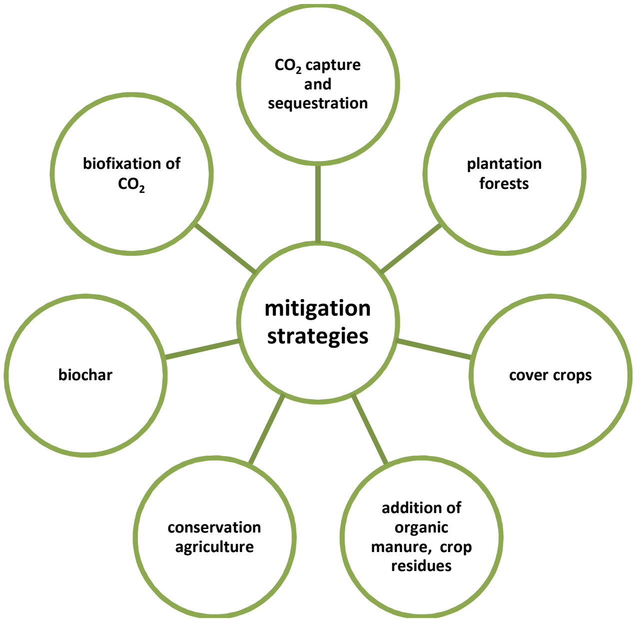

Fig. 3. Mitigation strategies

A previous study determined carbon storage in pine plantations located in the Eastern Highlands of Zimbabwe and found that carbon content varied irregularly during a 25 yr period. Carbon and N declined after establishment but recovered rapidly at 10 years, declined after silvicultural operations and recovered again after 25 years. The mean soil carbon among *Pinus* stands was 11.4 kg C m^{-2} with a maximum carbon content at 10 years (13.7 of C kg m^{-2}) and minimum at 1 year (9.9 kg of C m^{-2}). Charcoal additions over a 25 year period contributed to stabilization of SOC [88].

Preservation of SOC is important since soil organic matter is essential for soil productivity. Adoption of agricultural management practices that promotes soil productivity and sustainable soil use are required for mitigation of climate change [89]. It was reported that carbon sequestration potential of paddy soils increased under management practices such as reduced/no tillage, increasing crop residue return, and increasing manure applications in China [90]. The inclusion of cover crops in cropping systems may be another way to increase SOC in agricultural soils. A potential global SOC sequestration of 0.12 Pg C yr^{-1} has been estimated from cover crop cultivation which would compensate for 8% of the direct annual greenhouse gas emissions from agriculture [91].

Management practices involving inorganic and organic fertilization are more efficient in carbon sequestration because long term cropping without the addition of chemical fertilizer or organic materials may greatly decrease SOC [92-94]. Agroforestry practices involving short rotations of Eucalyptus and Leucaena plantations also have a huge potential to sequester carbon to the extent of 10 Mg/ha/y [93]. A study found that among five studied tree species, *Leucaena leucacephala* was the most suitable tree species for afforestation with higher carbon sequestration rates and SOC stability [95]. The surface soil carbon sequestration rates for the five trees varied from 0.13 tons/ha/yr to 0.47 tons/ha/yr after 20 yrs afforestation [95]. Higher soil carbon stock which varied from 20.59 to 50.45 Mg/ha/yr was reported for *Jatropha curcas L.* plantation sites in central India [96].

Soil amendments such as biochar have been identified to have potentials to sequester carbon in soils. A recent study has estimated that biochar has the potential to sequester 0.55 Pg CO_2 yr^{-1} in soils over long time periods [97]. A similar study showed that biochar made from *Eucalyptus camaldulensis* decreased GHG emission and increased soil carbon stocks by 1.87–13.37 t C/ha in Thailand paddy soil [98]. Microorganisms have also been used to sequester carbon through a process called biofixation. Biofixation of CO_2 by microalgae enables direct utilization of CO_2 from the atmosphere [99]. This involves biological C mitigation where CO_2 from the flue gases of point sources is used to cultivate photosynthetic autotrophic organisms and resulting biomass converted into biofuels, biochemicals, food or animal feed [100]. It is important to note that the whole process of photosynthesis is biofixation since carbon is converted to organic forms within plant tissues.

Urban areas are responsible for around three quarters of global energy use and energy-related greenhouse gas emissions [101]. Adoption of low emission development strategies by cities may be the key to climate change mitigation in urban areas. But many cities in developing countries lack the institutional, financial and technical capacities needed to switch to low emission development paths [102]. Low emission strategies for cities require cooperation and coordination between different institutional levels of governance to be effective.

5.1.2 Methane and nitrous oxide emissions

Mitigation of climate change will not be complete without a reduction in emission of other greenhouse gases like CH_4 and N_2O. For example, CH_4 emission accounts for 20% of global warming and climate change [103] and its major source is rice cultivation due to anaerobic environments in which rice is grown. The potential of rice paddy soils to emit CH_4 and N_2O depends on the redox potential [104]. A past study reported that reduction in emission of these two greenhouse gases cannot be done simultaneously because the redox potential changes with depth; however, appropriate water and residue management can reduce greenhouse gas emissions [104]. This does not agree with the findings of [105] who reported that the combination of drainage before topdressing and a stepwise decrease in topdressing reduced emissions of both CH_4 and N_2O from rice fields supplemented with aerated liquid fraction of cattle slurry.

Effective water management may reduce greenhouse gas emissions from rice fields. Total

CH_4 emissions from paddy field under controlled irrigation were reduced by 79.1% on average compared with continuous flooding irrigation during the rice growing period. However, the N_2O emission under controlled irrigation was mostly larger than those from flooding irrigation during the rice growing period [106]. Aerobic rice, a production system where rice is grown in well drained, non puddle and non-saturated soils; enhances yield, saves water, eliminates the methane emissions and reduces the nitrous oxide emissions.

Fertilizer management may also influence emission of greenhouse gases. In a three year field experiment, more than 65% of the annual N_2O emission from a maize–wheat rotation under different fertilizer regimes occurred during the maize growing season. Results show that the combined application of compost with inorganic fertilizer significantly reduced N_2O emission from soils in the North China plain [107]. Methods of fertilizer application may influence GHG emissions in rice fields. Deep placement of urea significantly reduced N_2O emissions compared with the urea applied by broadcasting in rice fields cultivated for three rice growing seasons in Bangladesh [108]. The addition of nitrification inhibitors such as dicyandiamide (DCD) to urea has also been shown to reduce N_2O emissions from irrigated rice in India [109]. A past study has concluded that the best mitigation strategy for methane emission amongst three proposed strategies; water management (mid-season drainage), fertilizer management and short duration rice varieties is the planting of short duration rice varieties [110].

Rotation of rice with crops such as maize and sweet sorghum have also been shown to reduce CH_4 emissions by 78–84%, and reduce net CO_2 equivalent emissions (CH_4 and N_2O) by 68–78% compared with sole rice [111]. Adoption of the no tillage system instead of the conventional tillage system in flooded rice fields can also reduce greenhouse gas emissions in a humid subtropical climate [112]. Conversion of rice paddies to vegetable production dramatically increased N_2O emissions from 0.59-1.90 kg N ha^{-1} in rice paddies to 55.5-160.1 kg N ha^{-1} in vegetable fields during a period of three years in China. Results suggest that soil organic matter and N mineralization contributed significantly to N_2O emission when rice paddies were converted to vegetable farms [113]. Hence, management practices that reduce the rate of organic matter and N mineralization may be used to reduce N_2O emissions in rice paddies.

5.2 Conservation Agriculture

Conservation agriculture involves practices which improve and sustain productivity, by ensuring minimal soil disturbance, permanent soil cover with organic matter or/and crop rotation [114]. Conservation agriculture can be used to mitigate effects of climate change because it involves practicing agriculture in such a way that there is minimum damage to the environment [115]. Conservation agriculture has a potential to increase crop yields as a result of a gradual increase of soil quality even under conditions of erratic rainfall [116]. Conservation agriculture includes practices such as conservation tillage techniques together with residue management and rotation [117].

Conventional tillage causes a physical breakdown of the soil structure which makes the soil susceptible to soil erosion [118-119]. Intensity of tillage practices increase the rate of organic matter decomposition leading to higher CO_2 emissions from soil to the atmosphere; however conservative tillage may be used to counteract this effect. In a study, under Mediterranean conditions, conservation tillage decreased CO_2 emissions and increased total SOC compared to traditional tillage [120]. Similarly, conservation tillage increased SOC and total nitrogen in the rain-fed farming areas of northern China [121]. Conservative tillage such as no tillage decreased overall CO_2 equivalent emissions and cumulative N_2O losses while crop rotation led to 31% mitigation of yield-scaled N_2O emissions in rain-fed semi-arid cropping systems [122]. A past study has shown that conservation agriculture-based wheat production system can cope better with the climatic extremes than the conventional tillage-based wheat production system in Haryana, India [123].

On-station and on-farm studies in Zimbabwe showed that conservation agriculture systems increased water infiltration by 331% and had a 31% greater soil carbon in the top 60 cm than on adjacent conventionally ploughed fields. There was also a 6% lower bulk density in the top 10 cm and 32.5–36 t ha^{-1} less cumulative soil erosion in conservation agriculture fields after seven cropping seasons compared with the conventional control treatment [124]. Maize rotation with leguminous crops such as cowpea and sunnhemp improved soil structure and fertility [124]. However, under high levels of residue retention there were greater macro fauna abundance and diversity than conventional agriculture, particularly termites [125]. In Tanzania, conservation agriculture systems had lower yield-scaled global warming potential averaging 62 to 68 % of the emission intensity of conventional practice [126].

Conservation agriculture was not as beneficial in a short term study in Zimbabwe. Conservation agriculture had a negative effect on crop yield both in on-farm trials with a cotton-sorghum rotation and in farmers' cotton fields. In a fine-textured soil, conservation agriculture had no significant effect on water run-off while in a coarser-textured soil; there was significantly more run-off under conservation agriculture in wet seasons probably due to soil surface crusting and soil compaction. The failure was attributed to poor crop management practices such as adequate fertilization, timely planting and crop protection which are pre-requisites for the principles of conservation agriculture to benefit smallholders under semi-arid conditions [127].

6. CASE STUDIES OF SELECTED COUNTRIES

6.1 Climate Change and Soil Productivity in Asia

6.1.1 China

Even though China is the world's largest GHG emitter, the country has goals of reducing these emissions and increasing non-fossil fuel sources to 20% of total energy by 2030 [128]. However, the high GHG emissions have already led to a changing climate in China. Over the past 50 yrs, the annual average air temperature has increased by 0.5–0.8°C which is slightly higher than the average global temperature increase [129]. On a regional basis, the warming trend was more significant in western, eastern, and northern China than in southern China [129]. Shandong Province, China's second most populous province is situated in the eastern part of China on the lower reaches of the Yellow River.

A situation analysis report on climate change in Shandong Province, China provided information about the effect of climate change on soil productivity in the region [130]. Climate change has reduced available water in the region through increased evaporation at the water surface, soil surface or plant surface because of temperature rise which increases water consumption. Temperature rose about the end of the 20th century which caused drought and increased crop water requirements in the region. The upward capillary rise in water to the soil surface and evaporation of water may be responsible for the salinization of soils in the region.

For example, in Laizhouwan region in Shandong, the climate warming has caused a reduced precipitation and a strong evaporation. A large proportion of the area is under the threat and impact of salinization, which occurs in spring. Presently, of the 8.1 million mu unused land in Yellow River Delta, 2.7 million mu land is saline and alkaline land. In the Yellow River Delta region in Shandong, the saline and alkaline land increases yearly by more than 6000 ha, making a large amount of land lie waste. Climate warming also causes sea level to rise which further spreads the salinity to the inland area. The salinity of soils of the Laizhouwan region is due to their location which is parallel to the coastline, with the salinization degree increasing in the direction from the inland to the sea.

Shandong has a farmland area of about 8.5×104 km^2 and an annual CO_2 emission involving about 1.95 million t C, CH_4 emission involving 0.055million t C, and N_2O emission involving 0.038million t N. The report estimated that N_2O emission has the largest contribution to the global warming potential (GWP) value of the farmland in Shandong, amounting to 68% of the total; while CO_2 emission is the second, at 26%; and CH_4 has the lowest contribution, accounting for only 3% of the total emissions. This was attributed to the cropping structure of Shandong that has a rather large proportion of vegetable planting area, which is the main source of N_2Oemission. The long term cropping in Shandong Province has also led to loss of soil organic carbon in the soils. Tillage practices in these farmlands enhance the decomposition of organic matter leading to loss of soil organic carbon.

The loss of soil carbon and salinity of soils has implications for crop production in the region. Even though, the report did not state the actual reduction in crop yield for the province, they predicted that the degradation of the soils will lead to lower crop yields. They explained that since a rise in temperature will increase organic matter decomposition, fertilization may be needed to sustain soil fertility. A warming climate may also increase incidence of pest, disease and weeds in farmland soils leading to the use of herbicides and pesticides. This indicates that climate change may increase cost of agricultural production. They reported that the warming climate has increased the frequency of extreme climate events and natural disasters in the province, which has caused an annual direct economic loss of several tens of billion Yuan, amounting to three-quarters of the GDP of the province [130].

6.1.2 Bangladesh

Bangladesh, located in south Asia is one of the most vulnerable to the impacts of climatic change because of its geographical location which consists mostly of floodplains. Some of the effects of climate change in Bangladesh include flooding, cyclones and storm surges, extreme temperature and drought, salinity intrusion which are responsible for reducing crop yields in the country [131]. Bangladesh is exposed to sea level rise due to its low lying nature. It has been estimated that one-tenth of the country lives in an area threatened by a 1 m sea level rise [132] and about 14,000 km^2 of land may be lost due to a sea level rise of 1.0 m. This will cause a lot of socio-economic problems such as migration of people from the coastal area further inland, which will put pressure on non-coastal area as well; there will be loss of livelihoods by affected population in coastal areas; huge economic losses to businesses in the coastal areas and economic burden to a government with limited financial resources to respond.

The impact of sea level rise on soil and water quality in the coastal areas of Bangladesh [133] indicated that about one-fourth of the population lives in the coastal area while others depend on activities in the coastal area. Sea level rise coupled with reduced flows from upland during winters will accelerate the saline water intrusion inland with coastal waters becoming more saline and soil salinity will increase. This was confirmed by the soil salinity map of the period of 1973 and 2000 which shows an intrusion of soil salinity in the coastal region. The map shows that soils of six regions were newly salinized in 37 years of time expansion. The map also shows that about 0.170 million ha (20.4%) new land is affected by different degrees of salinity during the last three decades. The same analysis [133] investigated the effect of soil salinization on agriculture in that country; more than 30% of the cultivable land in Bangladesh in the coastal area, about 1.0 million ha of arable lands out of 2.86 million hectares of coastal and offshore lands are affected by varying degrees of salinity [134]. Most of the lands remain fallow in the dry season (January-May) because of soil salinity, lack of good quality irrigation water and late draining condition [135]. Soil salinity decreased the germination rate of some plants, reduced rice yields in some villages and total loss of rice production (rice fields converted to shrimp pond) was reported in some other villages in the region [136-137]. A past study has suggested that increased salinity alone from a 0.3 meter sea level rise will cause a net reduction of 0.5 million metric tons of rice production [138].

Hossain MA [133] proposed land use planning as a management tool to reduce the effects of a climate change induced sea level rise in Bangladesh. He explained that land should be zoned on the basis of suitability; the most suitable zone, a moderate suitable zone and an unsuitable zone for different land uses. [139] recommended adaptive options such as control of saline water intrusion into agricultural land, coastal afforestation, cultivation of saline tolerant crops, homestead and floating gardening, embankment cropping and increase of income through alternative livelihoods for sustainable coastal agricultural development.

Even though the environment policy of 1992 of Bangladesh has recognized the need to address climate change, very few of the elements of the environment policy are yet to be translated into laws [140]. Environmental laws are needed to protect and preserve the environment. Without laws, there is nothing to enforce and we cannot talk about compliance either. [140] have reported that the implementation of environmental laws and regulations are weak and public awareness level is very low in Bangladesh. They added that the major limitation of the environmental laws is its silence on the standards, parameters, emission levels and management elements.

6.2 Conservation Agriculture and Carbon Stocks in Africa

6.2.1 Zambia

Gambia, located in Southern Africa is 1000-1600 m above sea level and has a tropical climate. There are two main seasons, the rainy season (November to April) and the dry season (May/June to October/November). The dry season is subdivided into the cool dry season (May/June to August), and the hot dry season (September to October/November). There was a slight increase in temperature from 1970-2000 showing warm rates per decade of 0.26°C to 0.48°C in agro-ecological zones of Zambia while annual rainfall declined from 1940-2005 [141].

This changing climate has impacts on the environment with occurrences of extreme climatic events such as droughts, floods, extreme heat and temperature in the country. The agricultural sector is negatively impacted by the change in climate with an increase in the incidence of hunger due to destruction of crops, reduction in cultivatable land and increased soil erosion [142]. This has affected the socio-economic status of the country since the agriculture sector generates about 18 to 20% of the country's Gross Domestic Product (GDP) and provides a livelihood for more than 60% of the population [142].

Conservation agriculture, as discussed earlier, is one of the mitigating strategies to counteract the negative effects of climate change in agroecosystems. Two on-farm studies were carried out in Zambia to investigate the effect of conservation agriculture on soil quality and maize productivity [143]. The first on-farm site was located in Malende Agriculture Camp (Malende) in Monze District, Southern Province of Zambia while the second was situated in Kayowozi Agriculture Camp (Kayowozi), Chipata District, Eastern Province of Zambia. The on-farm studies were conducted on farmers' fields with a total of six farmers hosting replicates of a validation trial at each site. Maize was planted in rotation with legumes such as soybean and cowpea in Malende, Zambia while at Kayowozi, Zambia, maize was planted as a sole crop, as well as rotated and intercropped with cowpea.

At Malende, treatments were conventional tillage with maize-legume rotation; conservation agriculture with no-tillage and maize seeded into legume residues and legumes into maize residues; and conservation agriculture with no-tillage and direct seeder. At Kayowozi, there were four treatments; conventional tillage with continuous maize; conservation agriculture plot with no-tillage and continuous sole maize with crop residues used as surface mulch; conservation agriculture with no-tillage and maize intercropped with cowpea with crop residues; and conservation agriculture with no-tillage and crop residue retention with maize-cowpea rotation.

There was a higher water infiltration rate and higher soil moisture under conservation agriculture than conventional tillage. This was attributed to minimum soil disturbance under no tillage and mulching by crop residues. Mulching reduces evaporation of water from the soil surface which increases soil moisture. Soil water conservation is important in places going through a drought as a result of climate change. Soil carbon improvements occurred where residues were retained without interference from fires or grazing animals. However, crop residue retention was a challenge to the farmers due to the loss of crop residues through human interference, termites and fast decomposing leguminous residues which may inhibit increases in soil organic carbon at these sites.

Soil organic carbon decreased in the conventional treatment with tillage and no organic matter input. At both sites, crop yield from the conservation agriculture treatment with rotation was largest in the long-term comparison. There were some challenges to conservation agriculture systems at the early stage because increases in crop yields may take between three to five seasons before they become significant. There were also concerns about the profitability of the conservation agriculture method.

6.2.2 Nigeria

Nigeria, the most populous country in Africa is situated in West Africa. The country has experienced a rise in temperature by 1.1°C and reduction in rainfall by 81 mm within the past 105 years [144]. The increasing temperature and decreasing rainfall led to frequent drought and desertification in northern Nigeria while coastal regions are subjected to sea level rise [144]. The main causes of climate change in Nigeria are urbanization, GHG emissions and deforestation. Carbon dioxide emissions in Nigeria are among the highest in the world mostly due to gas flaring in the Niger-Delta where crude oil is extracted and processed [145]. Deforestation is one of the primary causes of climate change in Nigeria because the country has one of the world's highest rate of deforestation of primary forests, where more than 50% of such forests have been lost in the past decades through unsustainable logging, agriculture, as well as fuel wood collection [146].

A study in Nigeria estimated soil carbon stocks and evaluated the effect of soil management practices on soil organic carbon [147]. Soil samples were collected from 10 sites with different management practices and edaphoclimatic properties in different parts of southeastern Nigeria. The soils were collected from different types of forests, grassland and arable land. The samples were collected at the end of the harvesting season in October when bulk density of tilled cropped fields had reverted to their pre-tillage conditions (because soil bulk density measurements are used for calculating carbon stocks).

Soil organic carbon is the key to soil productivity as discussed earlier because soil organic matter influences soil physical, chemical and biological properties that promote crop growth. Land use and management practices may either preserve or deplete soil carbon. The highest SOC content (3.07%) was found in the natural undisturbed forest while the lowest S0C (0.81%) was observed in the conventionally tilled, continuously cropped plot. This shows that tillage and continuous cropping adversely affects SOC by reducing carbon storage in the soil. Plots under conservation tillage and natural floodplains however had high SOC. Similarly, the highest total N (0.29-1.95 Mg kg^{-1}) content of the soils was found in either artificially planted forests or natural undisturbed forests while the lowest N content were found in plots that were conventionally and continuously tilled.

The highest carbon stock of 9510.9, 8987.8 and 7906.6 g C m^{-2} was found in the natural undisturbed forest, artificial forest and artificial grassland respectively. This shows that forests and grasslands have the greatest potential for carbon sequestration. The quantity of carbon stored in the natural forest was greater than that of the artificial forest by 5% probably because of greater diversity of plant species found at the natural forests and to a lesser extent because the natural forests are older than the artificial forests. The lowest carbon stocks of 1978.5, 2822.4 and 2768.7 g C m^{-2} were found in conventionally tilled and continuously cropped plots. There was a 71% depletion in carbon stock in the conventionally-tilled, and continuously-cropped plots relative to the highest carbon stock. [147] reported that large-scale conversion of forests to croplands in southeastern Nigeria may lead to 50-75% loss in the regional soil carbon stock. This may also further exacerbate the effects of climate change in the country.

7. The Way Forward

There is a need for effective land use planning and management by government bodies to prevent land use changes that deplete soil carbon stocks like the conversion of forestland to arable land. Policymakers in developing countries need to develop policies that will protect the environment and reduce deforestation and other environmental problems. Developing countries are particularly lagging behind in enacting and enforcing environmental laws. After laws have been created, it is the duty of government to enforce it and ensure compliance. The governments of developing countries need to adopt low emission strategies at local and national levels like their developed country counterparts. There is a need for the government to discourage and reduce reliance on solid fuel or fossil fuel to reduce greenhouse gas emissions. The government can do this by sponsoring research into alternative energy sources. There is also a need to find ways of communicating research findings with the farmers to improve crop yield and profitability. Governments need to support farmers and help them adapt to the changing climate in their various locations by providing modern weather stations that can give accurate forecast to alert farmers; provide heat and drought tolerant crop varieties in regions experiencing extreme heat and drought; and provide incentives to farmers. Farmers need access to funding to be able to adapt to the impact of climate change. The government can step in to provide financial help to farmers to ensure food security of their country. Farmers need to adapt to climate change conditions by adopting soil and water conservation measures that will preserve soil moisture and increase soil organic carbon.

8. CONCLUSION

The effects of climate change are very obvious with reports of extreme heat, flooding, cyclones and mudslides. Severe heat and drought has led to a reduction in crop yields which has affected food security and rural livelihood in developing countries. Agriculture is the most affected sector in developing countries because they practice rain-fed agriculture and most are dependent on farming for income. Crop production is strongly dependent on soil productivity indices such as organic matter content, soil available water, clay content and soil pH. Increasing temperature can lead to low soil organic matter which indicates low soil productivity. Rise in sea level due to global warming has caused soil salinity in coastal regions of Asia while extreme temperatures have increased desertification in sub-Saharan Africa. Deforestation greatly reduces soil carbon stocks and contributes to increasing GHG in the atmosphere. Sequestration of carbon in the soil, trees and microorganisms will lead to lower CO_2 emissions and reduce global warming. Adoption of management practices such as conservation agriculture that increase soil organic carbon, water infiltration and available soil water will improve soil productivity and reduce economic losses due to climate change. Greenhouse gas emissions in rice paddies can be reduced through water management, fertilizer management and conservation tillage. Climate change has caused numerous socio-economic problems such as loss of livelihoods, loss of farmlands, and structures/buildings which has devastated communities in many developing countries in the tropic and sub-tropics of Africa and Asia. There is a need for environmental laws to minimize impacts of climate change on food security and economic development in developing countries.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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