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Climate smart agriculture in sub-Saharan Africa: Role of arbuscular mycorrhiza fungi

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Abstract

Climate change affects many areas of human lives, including agriculture. Interestingly, agriculture contributes to climate change, necessitating climate smart approaches to ensure a win-win situation; wherein agricultural production is sustainable and meets current and future needs. Climate smart agriculture is a collection of agricultural practices that increase productivity, adaptation, and mitigation of climate change contribution to agriculture. While many global regions depend on agriculture directly and indirectly, the sub-Saharan Africa region is directly dependent on agriculture. Existing "climate smart" activities in this region must be better defined and strengthened to achieve its objectives – increasing agricultural productivity, adapting agricultural systems, and mitigating emissions from agricultural activities. Among these climate smart activities are the significance of soil microorganisms, particularly arbuscular mycorrhizal fungi in sustainable agricultural systems, where they provide limited plant nutrients, control pests and diseases, aid drought adaptation, improve soil structure, reduce nutrient loss during leaching, leading to sustainable soil management.

Keywords: Agroecology; Climate change; Mycorrhiza fungi; Soil management; Sustainability

1 Introduction

Climate change is a worldwide phenomenon, just like any natural occurrence that falls on both the affluent and the non-affluent, has no distinguished boundaries, and characterized by high uncertainty. This uncertain nature makes it difficult to plan adequately in tackling the issue. The United Nations Sustainable Development Goals (SDGs) [1] has its 13th goal to combat climate change and its impacts. Climate change affects every household, community, state, country, and continent, causing a lot of disruptions and cost implications to all individuals and groups, but it is not wrong to say that human activities have been major contributors to the climate. With adaptation being embraced faster, more use of renewable energy, and other efforts in place, hopes are high that climate change will be abated [1]. Yet, the degree or rate of adaptation differs greatly in all regions of the world especially in terms of proactive and reactive levels of adaptation.

The world has been feeling these impacts of climate change already, which will get severe in the mid-century, with the most hit region being the sub-Saharan Africa (SSA) [2-3]. This region, although characterized with high economic growth rates in the last few years, faces issues including unemployment, health care, education, government corruption, crime, access to clean water, and energy shortages, according to Pews Research Center [4], where agriculture and food supply is only seen as a priority by 9 – 25% of respondents. The SSA region is also known for serious environmental issues which need to be seriously examined and a sustainable economic development put in place. Among these issues are deforestation, soil degradation, and desertification, which is partly due to an interconnected chain of rapid

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population growth, survival, and poverty. Additionally, with increase in the prices of imported energy products, the forest has been strained uncontrollably [5], another addition to the climate change phenomenon.

Planning in this region should have climate change as a priority compared to other regions, to support climate-resilient development, but this remains at the peripheral stage. Climate information, even if available, are not based for related policies, because the priority in these regions are economic growth and development, where tangible investment returns are seen, especially on a short-term, and the ministries, e.g. environment, resource management where climate would have been a priority are seen to consume more with little to no return on investments [3]. Well, this time is passing already as climate change is now having a say in the economy and investments worldwide, besides investments on the environment pays for the long term. This study hence addresses the role and influence of arbuscular mycorrhiza fungi in agriculture in sub-Saharan Africa and the sustainability of this approach.

2 Material and methods

Analysis of research articles relating to topic from 2010 to date was made. This included over 70 journal articles, research theses and book chapters. These were summarised under specific topics on the overview of climate smart agriculture (CSA), climate change and agriculture in sub-Saharan Africa, climate change effects on agriculture, adaptation strategies for climate change for sustainable agriculture, climate smart agriculture in sub-Saharan Africa, ecological role of fungi in climate smart agriculture, and arbuscular mycorrhizal fungi role in climate smart agriculture.

3 Results and discussion

3.1 Overview of Climate Smart Agriculture (CSA)

Climate smart agriculture (CSA) addresses the challenges of climate change to food security in all regions of the world by targeting increased agricultural productivity, adaptation of agricultural systems, and lowered greenhouse gas emissions from agricultural activities [6]. CSA is defined by the proposed outcomes, and not the actual farming practices, because the practices are not new, it is the focus that is different, based on climate variation [7]. CSA has recently achieved much prominence, based on its objectives which are pertinent to human survival [8]. The emphasis on each objective differs in different regions, as productivity and adaptation are foremost in some regions, while mitigation may be the focus in other regions, therefore, the specific needs in a region towards climate smart agriculture must be identified and addressed. Agriculture and climate change are so interrelated such that the latter affects the former, and the former affects the latter. Thus, CSA helps to ameliorate the negative effect of their interrelations on each another; as agriculture is directly linked to food security. Several entry points for CSA objectives of productivity, adaptation, and mitigation involve the CSA practices, system approaches, and enabling environments [6]. It considers locally adapted interventions towards getting value from agricultural production, these are achieved by strengthening knowledge of sustainable agricultural practices and economic options, and improving farmers' ability to access agricultural resources [9].

The term has been used so freely that almost all agricultural practices that improve production in terms of food security have been termed CSA, even if the practices do not mitigate the climate change effects. CSA is not so holistic when it comes to biodiversity loss, ecosystem services, broad social, political, and cultural issues, and even global focus which could become inimical in the long run [10]; the voluntary adoption is quite low among farmers, and adoption based on incentives is higher [7], showing that there is a long way to go to achieve its objectives. CSA helps farmers to be proactive to reduce contributions to climate change, and ensure food security for the populace. Food remains the most important physiological need of the population, and every risk to food security has to be averted [11]. CSA aims to maximize food security, while significantly mitigating climate change effects and adapting where necessary. However, maximizing food security takes preeminence in developing countries, and adaptation is mainly geared to achieve this [12]. It is a global area where all nations must continue to collaborate to ensure that objectives are achieved faster and the efficiency of every effort is maximized [13].

3.2 Climate Change and Agriculture in Sub-Saharan Africa

Agriculture is intricately linked with climatic conditions, as it is almost totally dependent on the climate, and one of the most affected by climate change. SSA is more affected by climate change compared to other regions of the world because of high temperatures characterized by low rainfall, high dependence on agriculture, slow technological growth which culminates into slow adaptation to solutions [14], and almost sudden visible effects of this. Climate change is caused majorly by greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs)), aerosols in the atmosphere and land use changes, and continues to be a threat to agricultural production.

Agriculture accounts for over 50% household income in Africa [15], and climate change has threatened agricultural systems with poor adaptation and exposure to climate hazards. Sub-Saharan Africa has been seriously hit, because adequate resources to adapt to the effects and impacts of climate change in agricultural production are lacking and agriculture is primarily rain-fed [16].

The line between human activity and global warming is very thin, and climate change and its impact is characterized by uncertainty [17]. This implies that general human activities have to be geared towards mitigating their contributions to the ever-changing climate. Agriculture cannot be ignored globally because it provides food, income, employment, raw materials, foreign exchange, among others; the basic production level globally, from which a single individual can profit immensely. Subsistence agriculture, which is practiced by a large proportion of Africa's workforce, produces a larger percentage of food from this region [18], and climate change is a critical hindrance in meeting the food needs of her teeming population. Unfortunately, the most vulnerable group remains the poor and subsistence farmers, who have little to no resources, and rely greatly on rain-fed agricultural systems to provide for the present [19]. Planning to mitigate the effects of climate change on agriculture is a wakeup call to farmers and other agriculture stakeholders in sub-Saharan Africa, through tactical and strategic adaptation strategies [20]. As a result of many interconnected causes of climate change, adaptation coupled with mitigation seems to be the main option in combating this phenomenon for sustainable agriculture.

3.3 Climate Change Effects on Agriculture

Climate change is reducing global agricultural production, yet this production is expected to double by 2050 [21]. Climate change has resulted in reduced yields and failed farms in recent years, and yields are projected to decline. ADHIKARI et al. [22] reported that maize yields in rain-fed systems in Africa are likely to decrease by 11% by 2055, a drastic decline that will require major improvements in the agricultural system to stall. It was also reported that, while other regions of the world have experienced significant increase in maize yields, the SSA has experienced stagnant or reduced maize yields [23]. Climate change will also cause significant changes in land, for instance, some areas will have increased water while others will experience scarcity of water.

Agriculture occurs in a managed ecosystem, and as a result of this, depends on human response to the effects of climate change [24]. Also, climate change effects are always direct and there is always a ripple effect of this, making it quite hard to determine to what extent a single action could reach. An instance of drought on livestock systems directly reduces the available water which indirectly reduces the available pasture for feed; the shortage of feed then leads to a high supply of livestock when the demand is low, to be able to cope with the shortage of feed, high supply is directly linked with low price, and as such the business becomes unprofitable for the farmers both in the present and in the future [25]. This effect may all encompass the threats faced by agricultural production from climate change.

The normal crop response to high levels of CO_2 is positive, because CO_2 is needed in the photosynthetic process, but the effects of climate change, especially high temperatures and irregular rainfall will cause a significant reduction in crop yield and threaten food production in many regions, especially the vulnerable ones [26]. Thus, the high CO_2 has resulted in increased photosynthesis and reduced transpiration, thereby plants consume more water for the same productivity, that is, water use is inefficient. Moreover, increased temperature and sunlight has resulted in faster plant growth, but high demand for irrigation, reduced runoff, and minimal groundwater recharge, leaving an overall impact of less available water, reduced yields, and more stress on water systems. Altered rainfall patterns also cause extreme conditions of soil moisture either in lack or in excess and culminating in lower yields of crops, poor water quality, and poor storage of water [27].

The effects of climate change on any environment depend largely on their direct dependence on the climatic variables, for instance, the SSA region is faced with marginal or no increase in food production leading to food insecurity [28]. Climate change has caused increasing fluctuations in agricultural production in Africa, where climatic variables in extreme conditions have destroyed some agricultural systems, resulting in economic loss, hunger, famine, and even migration. Increased climate change is speculated to worsen food security in Africa due to soil infertility in arid areas [29].

3.4 Adaptation Strategies for Climate Change for Sustainable Agriculture

Adaptation to climate change is as important as climate change, being a policy option to climate change response. Because of high reliance of agriculture on climate, it has been really threatened by the climate change phenomenon, adaptation is therefore necessary for enhanced agricultural production [30]. Agricultural adaptation is effective at managing issues stemming from ongoing climate change, and its research must be innovative, and be applied at short and long time frames [31].

A number of studies have reported knowledge and adaptation of farmers in sub-Sahara African countries on climate change [32-35]. MUNTHALI et al. [32] reported that farmers knowledge of climate change is based on their experiences with their farm output; and how increased finance resources will help them adapt better. Collective learning of adaptation methods by farmers in certain places will ensure sustainability in adaptation [33]. ODONKOR et al. [35] also noted the influence of education to adapt better to climate change. The perception of farmers to climate change either at low levels or high levels has made them adopt some adaptation strategies to ensure their livelihood means [36]. Adaptation ranges from simple to complex approaches, for example, changes in simple production practices to transformed farming systems. Adaptation allows for a long-lasting and effective response as well as risk management to the ongoing climate change issue by farmers and other stakeholders [33]. It is a means that may not end, and estimates of climate change effects and impacts must be reliable so that adaptation efforts will tackle and address them effectively [32].

Improved agricultural production through adaptation will alleviate the climate change effects of warming, giving room for intensive sustainable inputs and adaptation measures [37]. Adaptive and coping strategies in smallholder agricultural systems include defining features of dryland livelihoods, maximizing biodiversity of wild plants and crops, integrating livestock with farming processes, maximizing yield on land, allocating farm inputs accordingly, diversified income generation, fallow systems use, improved storage mechanisms, among others [38-39]. A major adaptive strategy is the focus on ecosystem conservation in agricultural systems, some of these steps include soil, water and plant nutrient management, water availability; another is improved crop variety for tolerance to extreme temperatures, varied water scarcity (drought) situations, floods, soil salinity, etc. [8].

Large cropping systems adapt by using improved seedlings that can resist heat and drought, reducing chemical fertilizer usage, water management that prevents loss of soil nutrients, time and location adjustments based on current climatic variables, mixed farming, resistance to pests and diseases, improving and maintaining soil fertility, incorporation of crop residues, and even harvest of water. These adaptation ways optimize the advantages of the climate phenomenon and mitigate the problems. Agricultural systems that have to do with animals have adaptations not quite as smooth as the cropping systems, but notable. Some of the adaptations here include pasture rotation for livestock, favoured breeding of more tolerant species, mixed farming, and supplementary feeds [40-41]. The simple yet significant use of cover crops reduces erosion, leaching, pest attacks, cost of weeding, and even leads to higher yields. Crop rotation and intercropping have also enhanced soil fertility, nutrient supply to plants, and yields significantly. The importance of organic over inorganic practices in agricultural production has been widely studied to promote sustainability both presently and in the future. The minimum or zero tillage system also allowed for soil water management and soil improvement which results in significant higher yields compared to conventional tillage systems [42].

Agroforestry also contributes to climate change adaptation [41]. Agroforestry improves soil fertility and water recycling during water conservation. Agroforestry promotes sustainable farming practices and it is cost-effective, improves crop production, harvest of both wood and non-wood products, enhances biodiversity on land, and are good carbon sinks [43]. This system also improves land productivity, soil structure and organic matter infiltration and sometimes higher yields [42]. Adapting to climate change in SSA also includes saving sufficient water in times of rainfall for use during dry periods and improving pasture management by livestock [11]. Adaptation as regards water situations should be prioritized as water stress is expected to rise significantly and the risk to agricultural production and food access from climate change effects of the increase in floods and drought is also on the rise [42]. Adapting natural systems to climate change and its extremes involve preventing damage to the systems, maximizing benefits from the change and coping mechanisms [44]. Adapting agriculture to future climate change requires urgency, to be better prepared and build resilience to cope with evolving changes [25].

3.5 Climate Smart Agriculture in Sub-Saharan Africa

The United Nations Sustainable Development Goal 2 aims to promote sustainable agriculture. This encompasses environmental protection, food availability, improved livelihoods for farmers and even overall development; because climate change strains the resources we depend on, and increases drought and flood risks [1]. CSA evolved over time as each individual farmer realized the need to improve yield for higher income, hence irrigation and other strategies. Some cropping practices which are mitigation measures include intercropping, water-saving measures, and mulching with crop residues, but these measures at the farm level could be insufficient with increased drought; making farmers' adaptation limited [45]. These approaches have not been holistic because they entailed mitigating the downsides of climate change without exploring the benefits of better seasons, making most of the farmers still vulnerable to the expected climate changes. CSA is now globally accepted and has a holistic focus in terms of sustaining and maximizing agriculture in the current global climate variations.

CSA incorporates improving smallholder agricultural systems in response to the climate change global situation. Improving agricultural production simultaneously increases food security [2]. Studies have shown that the economy depends almost completely on agriculture, and agriculture will only survive by adaptation [46-47]. However, technology adoption including irrigation technology, capital interventions, and improved variety is very slow, because interventions either come late or are absent. Governments and other stakeholder organizations need to be highly proactive in their interventions as it does cost less both in cash and in effect, as prevention is “cheaper” than cure. CSA helps farmers increase food production, become more resilient to climate change, and reduce greenhouse gas emissions.

The national Agricultural investment plans in a number of countries in sub-Saharan Africa show that climate smart activities have been in place over time, and analyzing the most promising options and strengthening them will help achieve the CSA objectives. For example, in Nigeria, the national agricultural Investment Plan has had 86% subprograms with increased adaptation to climate change, 50% increased resilience of the agricultural system, and 75% increased economic contributions [12]. There are a number of limitations for the adoption of sustainable practices in sub-Saharan Africa, which are a result of disconnection of interventions from local farmers, where they are not intricately involved in the design, adaptation and test of new sustainable measures, which will also come at low cost to them [2].

CSA was adopted as a framework where sustainable agricultural systems can be implemented globally since 2010. While it is a relatively new concept in climate change and agriculture, CSA includes many of the sustainable agricultural practices both reported and in wide use, such as reduced tillage, agroforestry, and residue management [48]. The concept has focused on effecting and improving these practices with increased climate variation, and these practices have to be intensified in the SSA region where present, and introduced where unavailable. Climate smart systems require institutional and policy interventions to be achieved in good times in sub-Saharan Africa [44].

3.6 Ecological Role of Fungi in Climate Smart Agriculture

Intensive agriculture has directly increased food production through the use of fertilizer applications, irrigation, and improved crop varieties. Some of these practices have, however, reduced biodiversity and caused eutrophication in waterbodies [49], and have left cropping systems weakened by extreme dependence on chemicals, causing soil degradation [50]. Organic agriculture is then a viable option to ensure sustainable agricultural production, and significantly lower contributions to climate change. Sustainable agricultural production implies improved soil health, fertility, and overall soil management; and improved sustainable soil system directly leads to improved sustainable agricultural systems. Soil biodiversity is important in crop production because of their beneficial role in soil fertility, a good indication of improved production, and of their contribution to ecosystem stability.

Improved growth and yield of crops are closely linked to the abundance and nature of soil microflora in the rhizosphere (the soil around the plant roots), which help overcome a number of limitations in conventional agricultural practices. Microorganisms are known to sustain a lot of life processes including the environment [51]. They comprise naturally occurring microbes which are naturally present or introduced into the soil ecosystem and include rhizobacteria, cyanobacteria, toxicant degrading microbes, bacteria, fungi and others. Adequate incorporation and management of these soil microorganisms yield significant benefits in agriculture [52]. Microorganisms including fungi greatly improve soil fertility and plant production. They are also employed in pest and disease control in agricultural systems [53]. This is a climate smart approach as the pesticides that contribute to climate change are minimized or eliminated. The disease-causing microbes are unfavoured where the beneficial soil microbial populations are in abundance; and competition makes the fittest organisms remain, and others, usually the disease-causing ones, are overcome [54].

Soil fungi are eukaryotes with thread-like structures called hyphae (group of hyphae is a mycelium) that function either as decomposers, mutualists or pathogens [55]. Of particular importance are the mutualists (mycorrhiza) that play key role in CSA. These mycorrhiza form symbiotic associations with plant roots by colonizing the root of the plants, and help plants roots reach depths in the soil to access limiting resources that are previously unreachable. Mycorrhiza are grouped either as ectomycorrhiza which are found on the external surface of the root; and endomycorrhiza which are within the root cells. They have been associated with plants for so long as revealed in fossil studies; and they have been found associated with over 80% of plant species [56]. Mycorrhiza play significant ecological role in nutrient cycling, nitrogen uptake, phosphorus uptake, water uptake, and ameliorating stress in plants, which in turn help plants better adapt with climate change. Mycorrhiza function in both natural and managed ecosystems in these beneficial ways, but issues limiting it include ploughing of soil which reduces fungi abundance, and fertilizer use which inhibits fungi functioning [57]. Thus, to achieve CSA with these fungi, it is necessary to minimize tillage and chemical usage. While fungi alone sustains plant ecosystems, the interactions with other soil organisms (e.g. bacterial-fungal interactions) are significant in CSA [58].

3.7 Arbuscular Mycorrhizal Fungi Role in Climate Smart Agriculture

The arbuscular mycorrhizal (AM) fungi are a major proportion of soil microbial organisms with great significance in low-input sustainable systems of crop production, where they are able to contribute naturally in inhibiting pathogens compared to other systems [59]. The high-input systems interfere greatly with soil microorganisms, cause nutrient imbalance in the soils, and are short term; whereas arbuscular mycorrhizal fungi (AMF) can achieve a balanced and sustainable soil system, which is essential for agriculture. The AMF form mutual associations with plant roots by supplying limiting nutrients, especially phosphorus to plants; while the plants supply carbohydrates from their root exudates, which the fungi require for their growth and metabolism.

A significant role of the AM fungi in CSA is the protection they offer plants against drought. They improve the soil structure, leading to sustainable soil management, and reduce the loss of nutrients during leaching [49]. The reduction in the usage of chemicals and energy as an effective method of reducing agriculture's contribution to climate change has made AMF role in CSA notable [60]. AMF also interact with bacteria in the soil, which not only have a positive influence on their growth, but also boosts the mycorrhizal symbiosis [61].

Arbuscular mycorrhizal fungi are endomycorrhiza, in the sub-Phylum Glomeromycota, well-established in plant roots and found in most major ecosystems. Having associated with over 80% of plant species [62], accounting for the major fraction of soil microorganisms, they play a very pertinent ecological role in soil ecosystems for food production [57]. AMF profit immensely from their association with plants because they obtain almost all, sometimes all their food from the hosts; but then, as with all mutual associations, they increase plant biomass, photosynthesis and as high as 20% plant photoassimilate. These mechanisms are of great ecological and agricultural significance [63].

AMF serve as carbon sinks in the soil, and they mobilize P and N, thus involved in the cycling of elements, and thereby improving agricultural productivity, adapting agricultural systems, and lowering greenhouse gas emissions from agricultural activities, a climate smart phenomenon. They are also beneficial to plants in non-nutritional ways such as mitigating the effects of drought, soil salinity, and soil pathogens, and improve soil structure [64-65]. AMF serve in ecosystem conservation, sustainable agricultural systems, and in food security, essential global issues that future survival hinges upon, considering emerging threats from climate change [62].

AMF are also of high interest in agricultural production in sub-Saharan Africa because, they have been studied in reclaiming and re-vegetating degraded lands [66]. Many plant species are used to propagate notable AMF species, for continued usage and inoculation of better species in specific scenarios. It is in this light that variations in AMF responses to plants are noted. For instance, maize responds better to AMF compared to wheat, and legumes respond better than grasses. Thus, maize is a good host plant for the propagation of AMF, which increases its abundance per unit of soil [67]. Study by ADEKANMBI [68] revealed varied spore counts of four different *Glomus* sp. propagated using similar conditions.

AMF produce their hyphae, arbuscules, vesicles and spores inside plant root cortex; which extends out of the root (except the arbuscules), thereby elongating the roots [56]. This makes the plant roots longer than they normally would be. The extension are much longer than the plant roots [69]. Longer plant roots result in deeper and wider penetration of soil, strength to withstand external forces which prolongs their life span, and ability to reach nutrients leached away from immediate reach. The long extraradical hyphae of AMF thus aid plant survival under climate change in SSA. Studies on water stress have revealed the impact of AMF in this region. The study by GHOLAMHOSEINI et al. [70] showed two *Glomus* species in their experiment increased plant growth in both mild and severe drought stress conditions. Plants inoculated with *G. mosseae* recorded higher yields compared to those inoculated with *G. hoi*. Similar experiment by ADEKANMBI [68] using *G. deserticola* showed its good adaptation to strengthening plant during water stress.

AMF easily function to mobilize nutrients from crop residues. HODGE and FITTER [71] in their study found that the AMF, *Glomus hoi* enhanced decomposition and increased N release of organic materials. Field trials have shown that AMF in plants improve nutrient uptake, growth, and resistance to stress and pathogens [62]. Although, highly dependent on plants for survival (obligate biotrophs), and not the same for plants, AMF are extremely beneficial [62] in sustainable agricultural systems. The phytoremediating potential of AMF is diverse. They have been involved in mitigating negative issues of soil infertility and soil pollution in the management of soil [72]. Plants depend on microbial activities during drought because microorganisms, including AMF, help them tolerate the condition by reducing the stress and increasing nutrient supply [73].

AMF also play key role in disease and pathogenic resistance [69, 74-75]. AMF species benefit host plants differently, yet studies have shown on average that plant performances are better when AMF are present than when not [68,76] due to the fact that they enhance the uptake of immobile nutrients in the soil, especially phosphorus [77].

4 Conclusion

Direct dependence on agriculture for food security in the SSA region requires climate smart approaches and other sustainable initiatives, to handle climate change effects in addition to economic problems facing this region. The overall aim of CSA is increased agricultural productivity, adaptation of agricultural systems, and lowered greenhouse gas emissions from agricultural activities. Proper planning in the SSA region by incorporating these adaptation strategies such as the wide use of AMF will combat this phenomenon for sustainable agriculture. Introduction of improved AMF species to farmers which will be propagated by them will ensure better coping mechanisms to biotic and abiotic stresses. By selecting more effective species for increased agricultural productivity, the sustainable impacts of AMF are enhanced and explored.

Compliance with Ethical Standards

Disclosure of Conflict of interest

No Conflict of interest to be disclosed.

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