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Potential Development of Biochar in Africa as an Adaptation Strategy to Climate Change Impact on Agriculture

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Abstract
One of the most important obstacles to increasing agricultural production yields worldwide, especially in developing economies such as those in Africa is the continued degradation of soils due to climate change. In response to this threat, one of the strategies advocated is biochar technology, which is one of the emerging sustainable and climate-friendly soil amendments. This article reviews a brief description of biochar, the advantages and disadvantages of its use, and the prospects for developing its potential impact on agricultural productivity in African countries with a case study in Burkina Faso. Biochar is mainly useful for soil carbon sequestration, increasing and maintaining soil fertility, environmental management, and as a renewable energy source. However, it can have secondary effects including negative impacts on human health, pollution, and water quality. Furthermore, the positive results of biochar use in Africa suggest a prospect for ensuring the feasibility of biochar technology in policy decisions as a sustainable alternative to agricultural land management in the combat against climate change. As recommendations, a combination of improved seed varieties, and SWC (Soil and Water Conservation) techniques with the application of Biochar will be a perfect innovation for an intelligent adaptation practice to the destructive action of climate change in agriculture.

JEL codes Q15 · Q16 · Q54

Keywords Africa · Adaptation strategies · Climate change · Biochar · Agriculture

Introduction

Climate change has rapidly become a considerable phenomenon with irreversible consequences on the environment, the survival of human society as well as economic activities (Heshmati 2021). It is now obvious that climate change is a time bomb for our planet. Particularly, the agricultural sector remains one of the most vulnerable and impacted economic sectors by the consequences of climate change because of its link to climate evolution (IPCC 2014). Changes in temperature and precipitation patterns caused by climate change result in significant agricultural losses (Karimi et al. 2018). Yet, the agricultural sector is recognized as the driver of development for nations and as the primary source of revenue in developing countries in Africa (Zhang et al. 2020). It is therefore imperative to focus on analyzing and addressing the threats to its development such as the threat of climate change to find adequate solutions.

Indeed, agriculture has long been considered as being under threat of climate hazards. However, it should be noted that agriculture and climate change interact with each other. As much as climate change affects agricultural activities (notably low agricultural yields), agricultural practices (through the emission of toxic gases into the atmosphere) have effects that aggravate the condition of climate change (Kavitha et al. 2018). The agriculture sector is the second sector that emits more greenhouse gases (18.4%) after the energy sector (73.2%)[1]. The IPCC (Intergovernmental

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[1] https://ourworldindata.org/emissions-by-sector

Panel on Climate Change) confirms this assertion by saying that agriculture is both a bulwark and a burden to climate change. For example, according to the report of IPCC (2019) agriculture and other land uses accounted for about 13% of CO_2 emissions, 44% of methane (CH_4) emissions, and 82% of nitrous oxide (N_2O) emissions between 2007 and 2016. The excess of these gases is however dangerous for the whole earth. In addition, the energy consumption along the agricultural activity from production to processing is also a source of emissions of gases such as nitrogen dioxide and carbon. The whole agricultural production chain of plants and animals is a powerful source of greenhouse gas emissions to the atmosphere and even the first of the major causes of global warming (Kavitha et al. 2018) and it is crucial to reduce CO_2 emissions from agricultural soils for climate change mitigation (Spokas 2010). Furthermore, agriculture is responsible for nutrient extraction and reduction of soil organic matter due to repeated harvesting of crops leading to soil degradation and depletion (Jatav et al. 2020). Therefore, agricultural production must also participate in the fight against climate change, as the intensification of agricultural production on a global scale is necessary to ensure food supply for a growing world population.

The two obvious recommendations for dealing with climate change in general and in the agricultural sector, in particular, are mitigation of greenhouse gas emissions and adaptation to these impacts by promoting sustainable agricultural practices. However, mitigation efforts seem to be in vain according to critical IPCC reports that only make urgent calls for action (IPCC 2022). Instead of agriculture being the source of greenhouse gas emissions, agricultural practices can also contribute to sequestering carbon in the soil, managing water availability for plants, and improving soil quality and health. Thus, ultimately this improvement is supposed to follow with the expected increase in agricultural yields and thus food availability and improved food security (IPCC 2019). However, there are agricultural practices that could be used to capture more carbon, as discussed by the IPCC. Among the practices proposed and highlighted especially in Africa, we have practices such as choices of species with strong root systems, agroforestry, soil and water conservation techniques (SWC), irrigation, improved seeds usage, limitation of tillage, better management of rotation cycles, optimization of residue management, planting of trees and hedges, nature-based solutions, mulching, etc. (Tobignaré et al. 2022; Kaboré et al. 2019; Alvar-Beltrán et al. 2020). The IPCC alerts on the role of agriculture in land degradation but also on the potential of the sector to sequester carbon in the soil. These pieces of evidence show us the importance of finding and exposing techniques, behaviors, and practices of carbon reduction in agriculture. Several methods and practices known as agricultural smart practices or sustainable agriculture have already been developed and put into practice (as noted in studies by Teklewold et al. 2013; Khonje et al. 2018; Tobignaré et al. 2022; Ayantunde et al. 2020). The application of one of these smart farming techniques or sustainable agriculture practices in the fight against climate change including the soil amendment called "biochar" finds its justification here. This climate-friendly soil amendment is in full development in agriculture as well as in research studies of its use as a sequester of greenhouse gases (such as CH_4, N_2O, NH_3, and CO_2) in the soil to produce negative carbon emissions in agriculture (Vithanage et al. 2015). So, we ask the following questions: How serving farmland with biochar will transform the evolution of agriculture productivity? Is biochar an indispensable hope to deal with climate change? What are the advantages and disadvantages of producing and using biochar? What are the potential future developments of biochar in Africa?

Biochar or "terra preta" is a carbon-rich soil amendment obtained from the pyrolysis of biomass (such as leaves and agricultural residues) in the absence or presence of little oxygen (Zhang et al. 2010; Baskar et al. 2019). Initially used for the purpose of climate change mitigation through soil carbon sequestration and reduction of greenhouse gas emission to the atmosphere, and improvement of soil fertility and health (for better productivity as well as pollution reduction) (Lehmann and Joseph 2009; Jatav et al. 2020). Biochar application can be a means to not only sequester carbon in the soil but also to restore essential organic matter lost with the removal of biomass from agricultural systems for energy production (Jatav et al. 2020). Thus, waste management and energy production are other main objectives that can motivate the application of biochar for environmental management and climate change mitigation (Lehmann and Joseph 2009). Furthermore, in economic terms, biochar can potentially provide a dual economic benefit: improving the agronomic and environmental sustainability of biomass production systems; and improving the economic sustainability of bioenergy companies by offsetting feedstock purchases with revenues from biochar sales (Wang et al. 2020). In sum, biochar can not only generate income but also enhance agricultural and environmental sustainability.

Several works around the world have already shown that biochar applications have positive responses for soil improvement (and thus increasing yields of several crops), soil remediation and water treatment, carbon sequestration, and for mitigation of greenhouse gas emissions (e.g. Salleh 2017; Palansooriya et al. 2019; Ramzani et al. 2017; Purakayastha et al. 2015; 2019; Wang et al. 2020, etc). For example, in China, the analysis of Ramzani et al. (2017) finds that soil amendment with the addition of biochar improved the selective growth of plants (Chenopodium quinoa Willd), physiological, chemical, and biochemical yield significantly by the application of soils with complex climatic conditions. The experiment conducted by Hossain et al. (2015) shows that the soil amended with biochar with 10 t per ha produces 21% more yield of Cherry Tomato than the soil amended only with sewage sludge. In Japan, the results of Ishimori et al. (2017) and Koyama and Hayashi (2017) are positive with an increase of 90% yields with biochar/Chicken manure and 14% of rice yields with biochar/Rice husk. However, the effect and stability of biochar mainly depend on the pyrolysis temperature, type of feedstock, and biochar application rate (Ding et al. 2017). These make several types of biochar affect soil GHG emissions in several ways (Oni et al. 2019). For example, Cross and Soli (2013) reported that the stability of "sugarcane bagasse" biochar increased when the pyrolysis temperature increased from 350 to 550 °C.

Although the majority of studies have provided positive results for biochar use, however, variable application rates, uncertain effects of the feedstocks used in biochar pyrolysis, and initial soil conditions provide a wide range of consequences for biochar use. For example, results from Mukherjee and Lal (2014) show that biochar use results in carbon and nitrogen leaching, yield loss, contaminant mobility, and several other adverse physical changes to the soil. In Germany, Reibe et al. (2015) found a decrease in wheat yields when using corn biochar. In Denmark, Bruun et al. (2012) find a 10% decrease in barley yields using biochar as a soil amendment. Fungo et al. (2017) found no effect of biochar in a two-year study on tropical soil. Nor did the results of Tammeorg et al. (2014) in Finland. Thus, these studies highlight the conflicting effects of biochar application as a soil amendment. In addition, other impacts of biochar use are impacts on water quality, air pollution, impact on food quality, and human health (Wang et al. 2019; Shabbir et al. 2021; Muhammad et al. 2020).

While the effect of biochar as a potent amendment in combating climate change in agriculture is often recognized as effective or ineffective, this research aims to highlight the potential development of biochar in Africa. This article is important on three points: one, as most of the review studies focus on other continents' countries, this study resumes the studies about biochar cases in Africa. Second, while most of the studies show us only the advantages of using biochar, this article brings together the advantages and desalinates of biochar. Finally, this study will improve the literature about biochar knowledge and biochar as a climate change adaptation and mitigation strategy. Thus, the remainder of the paper is organized as follows: A brief description of biochar is first reviewed, followed by the advantages and disadvantages of using biochar. We then analyze the potential development of biochar in Africa and presented a case study in Burkina Faso. Finally, we discuss the prospects for future development of the use of biochar in agriculture and we end with potential policy suggestions and the conclusion.

Brief Description of Biochar

Although research on the use of biochar is a recent development, it is however not a new product with these multiple advantages and disadvantages (Lehman and Joseph 2009). Indeed, the origin of biochar or "Terra Preta" in Portuguese goes back to the black soils of the Amazon region where all the waste was almost organic more than 6000 years ago (Lehman and Joseph 2009). The formation of this wealth is the fruit of the ancestral practices of this conservative society which consisted in burning under a layer of the earth without exposure to the air the rest of the meals, the fish stops, the manure, the debris of pottery as well as other residues to regenerate forests from agricultural land (Macedo et al. 2017). These lands with exceptional properties were very rich in carbon, phosphorus, calcium, magnesium, zinc, manganese, and organic debris (Barbosa et al. 2020).

Nowadays, biochar is a porous organic product that is produced by the thermal decomposition of biomass under a limited supply of oxygen (O_2) and at relatively low temperatures (below 700 °C) (Lehman et al. 2009). There are various types of pyrolysis processes for biochar production that may include slow or fast pyrolysis, gasification, and torrefaction (Brassard et al. 2016; Patel et al. 2019). Today, the biomasses used in the manufacturing process of biochar are of large and great divergence so there is a different type of biochar with different physical and chemical properties as well as the final quality of the product (Wang et al. 2020). They include rice husks and straw, leftover corn cobs, leaves, cotton stalks, sesame stalks, corn rachis, groundnut shells, sorghum stalks, sunflower, millet, soybean, bagasse of sugar cane, cocoa pod, bamboo, dry palm, palm stem, logging residues, poultry hay, urban waste and so one (Li et al. 2013; Khorram et al. 2015). So, using these wastes to produce biochar is an effective means to transform waste into valuable and useful products. Biochar, this carbon-rich component, is used in agriculture all over the world and in Africa with the aim of maintaining the level of soil fertility over many years, even up to five hundred years according to studies (Hawken 2018).

Using Biochar in Agriculture: Advantages and Disadvantages

Climate change and variability are leading to agricultural soil degradation. Extreme events such as heavy rains and winds, flooding, and soil erosion deplete farmland of nutrients and

Table 1 Advantages of using biochar in agriculture

Function	Combat	Advantages
Water retention	Fight against drought	Water retention makes soils more resistant to drought and allows plants to have needed water and reduces the need for irrigation
Nutrient retention	Fight against soil infertility	Improves soil fertility and limits the need for manures and fertilizers
Improved productivity	Fight against yield decrease	Helps increase yields and fight against food insecurity
Carbon reservoir/sink	Fight against climate change	Carbon Sequestration
Lasts a long time on the ground	Fight against the lack of soil amendment	Long term investment
Waste management	Environmental Pollution Control	Environmental management, holy environment, pollution reduction
Produces energy	Fight against the energy gap	Satisfying energy needs

Source: Author

lead to soil depletion. The land becomes infertile and production yields decrease. Thus, to fight and face this threat, the investigation of innovative solutions which can constitute to maintain the productivity and the profitability of the cultures has led to the discovery of the technique biochar. The latter is generally praised for its multiple advantages (Smith 2016, Lompo et al. 2021). However, by observing the chain of manufacture to the use of such a product, it remains noted that it has as well advantages and disadvantages (Fuss et al. 2018). It is then essential to focus on the general analysis of these different cases (advantages and disadvantages of biochar) in order to put attention to the use and development of biochar.

Advantages of Biochar

Organic matter is important in sustainable soil management. Therefore, based on its multiple functions, biochar can enhance agriculture soil quality in various ways. In general, biochar used as an agricultural soil amendment is seen as a sustainable strategy to reduce the release of greenhouse gases into the atmosphere, improve soil fertility and quality and increase agricultural yields around the world (Lehmann and Joseph 2009, Lehman et al. 2011). The use of biochar makes it possible to strengthen the resilience of agricultural land to extreme climatic phenomena. Biochar is a solution that has already proven itself in the sequestration of carbon in the soil in the improvement of agricultural production. It promotes long-term soil health. Most of the literature (e.g. Rees 2014; Oni et al. 2019; Ding et al. 2016; Nair et al. 2017; Guo 2020; Jeffery et al. 2016; Brassard et al. 2016) reports the many advantages and efficiencies of applying biochar as a soil amendment (See Table 1). These multifaceted properties mainly depend on the type of biomass used, the pyrolysis time, and temperature (Ding et al. 2016). Indeed, biochar is used as a soil amendment aimed at improving the physical, chemical, and biological properties of the soil while combating drought and the need for plant irrigation (Rees 2014). Although the physical and chemical characteristics of biochar vary from one biochar to another (Lehmann and Joseph 2009), the porosity, the bulk density, and the water retention capacity in the soil are the physical properties of the soil on which biochar acts and improves (Blanco-Canqui 2017; Guo 2020). The biochar by promoting the porosity of the soil facilitates its oxygen supply and increases the water retention capacity. As for the chemical properties, biochar actively absorbs nutrients such as ammonium and nitrate and reduces emissions of these gases to the atmosphere (Jeffery et al. 2016). It is said that biochar can reduce carbon dioxide emissions by 0.8 gigatons by 2050 and 72nd in terms of good practice ranking in the fight against climate change (Hawken 2018). Thus, it is a nutrient reservoir and carbon storage in the soil rather than a greenhouse gas emitter. However, biochar makes it possible to compensate for the nitrogen content lost by leaching from the soil when it is left in the open air after pyrolysis until the pores are completely saturated with nitrogen (Angst et al. 2013). Thus, according to Zhang et al. (2015), biochar is generally composed of carbon, oxygen, and nitrogen. By improving soil quality through its nutrient retention capacity necessary for plants, biochar fights against soil infertility and improves agricultural productivity, increasing average agricultural yields by 15% (Hawken 2018). Furthermore, the contribution of biochar in the management of waste streams from animals and plants (fighting environmental pollution) as well as in the production of green energy is however not negligible (Khorram et al. 2015). The waste materials used in the manufacture of biochar as agricultural charcoal or as a source of energy are valued instead of being the cause of environmental pollution (Barrow 2012). Unlike soil fertilizers such as organic manure and compost, one of the advantages of biochar is that it is a profitable and long-term investment reducing production costs. It persists in the soil for as long as possible (up to 500 years) to exert a lasting effect on soil properties (Guo 2020).

Disadvantages of Biochar

As shown above, most of the research presented the advantages of biochar. But, on the agricultural, environmental, and human levels, the use of biochar has also negative consequences and disadvantages that have been mentioned only in a few studies. Biochar as a soil amendment does not always benefit agricultural productivity (Kuppusamy et al. 2016). Indeed, the effectiveness of biochar depends on several factors, in particular the pyrolysis temperature, the feedstock, and the rate of application of biochar (Ding et al. 2017; Ahmadvand and Soltani 2020). The application of very high doses of biochar is harmful and reduces the growth of certain plants resulting in low-yield inputs due to the alkaline content of the biochar (Prapagdee and Tawinteung 2017). Therefore, Co-composting is recommended by several authors for the effective application of the product (Du et al. 2019; Wang et al. 2017). This consists of mixing the biochar with organic matter such as manure before the aerobic process (Vandecasteele et al. 2016). This process improves the agronomic nutrient capacities of biochar but also reduces the losses of greenhouse gas emissions to the atmosphere (Du et al. 2019). Other studies also show that biochar combined with nitrogen fertilizer is more effective than just applied biochar. These results as well as the proposals to combine biochar with other substances come here to reinforce the results of certain studies (Teklewold et al. 2013. Khonje et al. 2018; Liang et al. 2021; Ng'ombe et al. 2017) on the potential of combining some adaptation strategies. Joint adoption of adaptation strategies including the combination of improved seed varieties adaptable to climate change, SWC techniques, and other techniques are potential techniques for agriculture adaptation. So, biochar use also is not useful sometimes but effective when combine with other products. For example, the results of Li et al. (2019) show that the application of biochar at 20 tons per hectare mixed with nitrogen fertilizer reduced residual nitrogen in the soil. However, even though biochar appears to be easy to produce from agricultural and municipal waste, several factors in the production of biochar can affect its role in environmental management. One of the disadvantages of using biochar is the choice and availability of large quantities of the biomasses to be used, ownership of the pyrolysis device, pyrolysis conditions, and labor availability (Khorram et al. 2015). Without any proper regulation and enforcement of feedstocks, stripping the earth of its biomass or cutting down trees will only damage or further degrade the soils and environment we are trying to restore (Hawken 2018).

In addition, several unanswered concerns undermine the effectiveness, advantages, and importance of the biochar mentioned above. Indeed, the use, especially on a large scale of biochar would have climatic impacts, impacts on the quality and the retention of water in the soil, impacts on agricultural yields, impacts on erosion and depletion soils, pollution impacts, and human health impacts (The African Biodiversity Network, Biofuelwatch and The Gaia Foundation 2010) (See Table 2). Based on these findings, it is possible that biochar contributes to aggravating climate change rather than reducing its impacts. For example, a field trial in Canada showed that no additional carbon was found in the soil after two years where biochar was incorporated compared to those where nothing was added (Husk and Major 2010). Biochar must be the subject of adequate analysis, especially for its real effectiveness.

Potential Development of Biochar in Africa

The agricultural sector and farmers constitute the backbone of the African economy. However, in Africa, the lands are degraded, relatively poor, and lacking in nutrients. Indeed, the challenge of African agriculture is to produce infertile soils to meet the needs of a growing population. So, the fertility of the land plays a key role in agricultural production and the level of yields in Africa. Biochar, this charcoal for agricultural use (not to be confused with cooking charcoal) proves to be an adequate solution for the nutrition and enrichment of these types of land with agricultural nutrients over a very long period according to certain studies (e.g. Manka'abusi et al. 2019; Akoto-Danso et al. 2019; Steiner et al. 2018. These studies show that the results of the use of biochar are optimum on degraded and acid soils generally found in regions of Africa where food insecurity is increasing. For most of the research, the analyzes were carried out by doing field and pot trials on the effectiveness of biochar in improving soil fertility yielded very positive results were founded (Berazneva 2013).

One of the first potentials for biochar development in Africa is the abundant availability of biomass used for pyrolysis. If not used for biochar production, disposal of this waste poses significant risks to public health and the environment (Gewinzi et al. 2015). Thus, the study by Omulo (2020) on the potential of biochar to increase agricultural production in East Africa finds that with the trends in the production of maize (the most cultivated product in the region) in the region, it is possible to generate enough biomass residues to produce a large quantity of biochar. So, the availability of abundant biomass residues (33.3 million tons of biochar per year with a total of 13.5 million tons of corn grown out of a total of 8, 1 million hectares) in this region is a great force to develop the application of biochar. This has the potential to reduce fertilizer use by farmers in the region by up to 30%, protecting them from exorbitant mineral fertilizers while achieving the desired yield (Omulo 2020). Zimbabwe produces about 9.9 Mt/yr of biochar feedstock, of which 98% is in the form of manure (8.7 Mt/yr) and firewood (1.0 Mt/yr). This waste, by slow pyrolysis, potentially produces around 3.5 Mt of biochar; 3.1 Mt of syngas, and 1.7 Mt of bio-oil per year (Gwinzi et al. 2015). With a recommended biochar application rate of 5 t/ha, Senegal has enough biomass available for biochar to cover all its cropland every 4.4–5.5 years (Faye et al. 2021).

Table 2 Impacts of the biochar usage

Impact factors	Implications
Climate impacts	-If tiny particles of charcoal powder are released into the air, either when biochar is incorporated into soils or later as a result of erosion, they can lead to significant global warming on a regional and global scale.
	-The carbon in charcoal is black, and airborne black carbon is one of the main causes of global warming.
	-Biochar additions in the soil make soils darker, which promotes increased heat absorption and helps amplify the effects of droughts and heat waves.
Impact on water quality	Toxins tend to stick to the charcoal, which could lead to leaching into the crops and therefore an increase in the level of toxins in the food (see Sohi et al. 2009)
Impact on agricultural yields	-The application of very high doses of biochar reduces the growth of certain plants resulting in low yields due to the alkaline content of the biochar (Prapagdee and Tawinteung 2017)
	-Fresh biochar contains ash and nutrients which are depleted after a short period of time. As a result, yield performance often initially improves and then drops (see Steiner et al. 2018)
	- Since biochar is not itself a fertilizer if most of the residues are turned into biochar rather than compost, it will create a dependence on other expensive and ecosystem-damaging synthetic fertilizers for farmers that contribute to further climate change.
Impacts on soil erosion and depletion	-Using crop residues to produce biochar rather than leaving them in the soil or turning them into compost could significantly accelerate soil erosion and depletion.
Impact on pollution	- Air pollution can also be a concern during pyrolysis, especially if the biomass has been treated with chemicals, contains other toxins, or is mixed with municipal solid waste, old tires, and other waste.
	- Charcoal retains and concentrates pollutants that could enter soils, waterways, and the food chain
Health impact	-A study showed that 30% of biochar escaped into the atmosphere when applied. Therefore, farmers and people living near areas where biochar is used are therefore at risk of contracting serious respiratory diseases (see Husk 2009)
	- Some biochar production projects, such as in Egypt, Ghana, and Senegal, involve burning rice husks. However, the dust generated by the ashes of rice husks is associated with silicosis, which is a lung disease with irreversible and progressive effects that causes emphysema and pulmonary fibrosis and often proves fatal (see Liu 1996; Baveye 2007).

Source: Compiled by the author from the information document "The African Biodiversity Network, Biofuelwatch, and The Gaia Foundation Second edition – December 2010"

Increasing crop yields due to the application of biochar have been observed in several studies in Africa (e.g. Yeboah et al. 2009; Utomo et al. 2011; Steiner et al. 2018; Häring et al. 2017; Akoto-Danso et al. 2019; Manka'abusi et al. 2019; Faye et al. 2021). These yield increases are generally associated with the ability of biochar to retain moisture and nutrients under the soil (Utomo et al. 2011). Thus, the results of Steiner et al. (2018) show that Tamale farmers in Ghana by adding biochar (from 0.9 t to 10.7 t/ha rice husk) to their normal farming practices, were able to increase lettuce yields by 93%. Using a simple top-lit updraft gasifier, a special chimney for rice husk carbonization, it was relatively simple for Tamale farmers to produce biochar in the field, with an efficiency of 15–33%. Another study in Tamale conducted by Akoto-Danso et al. (2019) analyzes the effects of applying mineral fertilizers and biochar amendment at two levels of water quality and quantity on soil moisture, plant nutrition, and the production of biomass on a Petrolinthic Cambisol over 2 years. Rice Husk Biochar applied at 20 t/ha significantly increased fresh matter yields in the first five crop cycles by 15% and 9% after 2 years. The yield-enhancing effects of biochar, on the other hand, disappeared over time. On the other hand, and still in the context of Ghana, a previous study by Yeboah et al. (2009) reported up to a 5% increase in nitrate recovery when biochar was applied to maize farms on sandy soil (showing the strength of nutrient retention by biochar).

Similarly, a single application of corn cob biochar at 20 t/ha was used in a 2-years study covering eleven crop cycles. As the results, biochar significantly improved total fresh matter yields of two cycles of amaranth by 39% and 17%, lettuce by 7%, and carrot by 11% in Ouagadougou/Burkina Faso (Manka'abusi et al. 2019). In contrast to these studies, the results of the analysis by Häring et al. (2017) were less pronounced compared to the previous study. Indeed, Häring et al. (2017) determine soil-biochar-wastewater interactions and fertilization over time in two types of sandy soils, depleted soil organic carbon (SOC) and nutrients in the context of urban vegetable production in Tamale (Ghana) and Ouagadougou (Burkina Faso) over two years experience as well. However, adding biochar to 2 kg m^2 made from rice husks and corn cobs initially doubled SOC stocks, but SOC losses of 35% subsequently occurred. Both types of biochar did not affect soil pH, phosphorus availability, and effective cation exchange capacity

(CEC), but in contrast, rice husk biochar retained nitrogen (N). In Senegal, applications of one-third to one-half the recommended national rate of NPK, in combination with 5–10 t/ha of rice cob or cow manure biochar, were performed. As a result, millet grain yields increased by up to four to five times more than normal (i.e. 100–450 kg/ha). This was equivalent to the yield of treatments receiving the full recommended national fertilizer rate without biochar. In addition, soil pH increased from 5.5 to 6.3 and carbon from 1.84% to an average of 2.69%. Biochar application alone did not increase millet yields (Faye et al. 2021).

In the experience conducted in Zambia, maize yield increases of between 80% and over 400% were observed on biochar-amended soil compared to control soils (Cornelissen et al. 2013). In three agroecological zones in Kenya, a study was conducted from 2013 to 2019 with a sample of 150 farmers. After two years of experimenting with the production and use of biochar, the results were promising. While 95% of respondents who participated in the tracer studies perceive improvements in crop yield, not only in quantitative but also qualitative terms, 77% report feeling positive impacts on energy efficiency (Mahmoud et al. 2021). Similarly, experimentation on degraded tropical soil in Kenya, demonstrated that biochar can restore soil quality and crop productivity. This is reflected in about 2.9 tons of additional yield on biochar-amended soil compared to control plots with fertilizer but without biochar (Kimetu et al. 2008). Soil characteristics and taro yield improved with a biochar level of 0–30 t/ha applied in Owo (southwestern Nigeria) to evaluate the effects of biochar produced from hardwood (Adekiya et al. 2020). Rogers et al. (2017) explore socio-economic factors that may explain avoidance trends in biochar adoption in the Mbeya and Songwe regions of Tanzania. The perceived increase in crop yields from 1 metric ton per hectare to 3 metric tons per hectare, assurance of food security, and increased family income were cited by farmers as the main reasons for engaging in biochar production and utilization in their agriculture activities.

Besides improving soil quality and productivity, biochar in Africa is also in line with the global effort to sequester soil carbon and reduce greenhouse gas emissions (Mukome et al. 2013, Gwengi et al. 2015). For example, using an estimated biochar carbon content of 63% and an annual biochar production of 3.5 Mt, land application of biochar could potentially sequester about 2.2 Mt per year of soil carbon in Zimbabwe alone (Gwenzi et al. 2015). The 0.85% increase in total stable carbon (from biochar) has the potential to sequester 27.2 tonnes of carbon per hectare in Senegal. If extended to Senegal's 1.6–2.0 million hectares of groundnut and millet cropland, the application of biochar technology could sequester 43.52–54.4 million tonnes of carbon. This has mutual benefits on crop productivity and climate change mitigation (Faye et al. 2021). The results of Fru et al. (2018) in Nkolbisson (in Cameroon) showed that farmers using rice husk biochar made more profit with net benefits of 1.44 million CFA francs and a marginal rate of return (MRR) of 33.06% compared to controls ones (583267fCFA) with an MRR of 12.33% and corn cob biochar (353436 fCFA) with an MRR of 7.80%. Additional revenue of 34.95% was derived from using the market price of rice biochar to offset CO_2 at $60.

Biochar represents a promising and scalable adsorbent for industrial applications and environmental remediation in Africa, as it is cheaper and easier to manufacture than activated charcoal. Furthermore, in combination with inexpensive drinking water coloring systems, biochar can be used as a low-cost adsorbent in water and wastewater treatment in Sub-Saharan Africa (Gwenzi et al. 2015). Given its ability to adsorb cationic and anionic compounds, biochar can be applied for the treatment of industrial effluents and urban stormwater before discharge into the environment (Gwenzi et al. 2015). The use of biochar in Africa is especially beneficial for small farmers. In addition to having a small size of the lands (often non-owners of it), the smallholder does not generally have access to credits and investments and even less the great means to invest fully in their agriculture activities and expect growth. Thus, the illustrated empirical evidence reinforces the feasibility and sufficiency of biochar technology to impact the agricultural performance of smallholder farmers in Africa in the challenge of the effects of climate change (Ndhlovu et al. 2017).

Overall, all these convergent and divergent results throughout the biochar application in African countries show that the effectiveness and expected impacts of biochar depend on several factors. These are the type of raw material used, the pyrolysis conditions, the physicochemical structures of the biochar as well as the biological one, the type of climate and soils on which it is applied, and of course, the quantity of biochar applied (Fan et al. 2021, Bakshi et al. 2016, Zang et al. 2020). Depending on all these factors, the effect of biochar with or without other fertilizers such as manure and NPK can be positive or negative and even neutral in agricultural activity. However, biochar technology and production knowledge, the lack of funding (public investments), appropriate policies, and the technological devices needed for pyrolysis are many constraints facing the biochar industry in Africa. Socio-economic barriers and risks (skepticism, perception, and attitude to adapt biochar technology) also exist (Gwenzi et al. 2015). Despite the existence of a multitude of biochar projects in Africa, currently, biochar research is limited in national research institutes and universities in Africa and ongoing research is at an embryonic stage compared to other parts of the world. More scientific research is needed to understand how to optimize biochar adoption in Africa.

The results and knowledge of this basic research will be the key components in shaping the position of biochar development in Africa (Gwenzi et al. 2015). Learning how to choose the most suitable biomass depending on the soil and the right pyrolysis process will make the use of biochar more useful, profitable, and effective in Africa as well. With proper adoption and implementation of biochar, guided by sound policies and good governance, biochar production has great potential to boost the production of farmers in Africa and improve their welfare (Omulo 2020). Table 3 summarizes some related studies (mentioned or not) conducted in the context of the use of biochar in Africa and their main founded results.

Case Study: Use of Biochar in the Hauts-Bassins Region of Burkina Faso

Methodology

Presentation of the study area

Located at 11° 16’ 48” North latitude and 4° 19’ 12” West longitude, the Hauts-Bassins region is a region located in the west of Burkina Faso. It covers a total area of 26,606 km² or 9.7% of the national territory (INSD 2019). It is the second metropolis and the economic capital of Burkina Faso and contributes 12.7% of the formation of the national GDP. The population of the region is growing from 1,469,604 in 2006, there were 2,371,465 inhabitants in 2021. The region has 3 provinces (Houet, Tuy, and Kénédougou), 3 urban communes, 33 departments, 30 rural communes, and 479 villages (INSD 2019). Economically, there is a diversity of economic activities in the informal sector. However, agriculture remains the most important activity (with the operation of small hectares), followed by animal husbandry and trade. According to INSD (2019) reports in the Hauts-Bassins region, agriculture is extensive and highly dependent on rainfall. In addition, it is very poorly mechanized with difficult access to agricultural inputs. Despite everything, the region is one of the most productive regions of the country. The region of the high basins is subject to the tropical climate regime of the northern Sudanese type, between the isohyets of 800 mm and 1100 mm, and characterized by the alternation of two (02) seasons: dry and rainy. However, climate change is a reality in the region and not insignificant. The yields of cereal crops are unstable and seem to vary according to the agri-climatic conditions of the same agricultural campaign and from one campaign to another. To cope with climate variability, adaptation strategies such as SWC techniques and biochar technology have been adopted, hence the choice and importance of this study area.

Data and method

The data used in this case study are essentially data from primary surveys carried out. The face-to-face surveys were carried out on a randomly selected sample of 384 farmers in the Hauts-Bassins region out of a total of 16 villages. Beforehand, a survey questionnaire was prepared, and preliminary studies are carried out. Reports of studies on climate change and adaptation strategies were viewed. Meetings with the provincial and departmental directorates of the DRAAH-HBS (Regional Directorate for Agriculture and Hydro-agricultural Development of the Hauts-Bassins) and the managers of the ProSol/GIZ project (Protection and rehabilitation of degraded soils) have been effective help in selecting and joining the villages. The question bank was divided as follows: socio-demographic characteristics of the households surveyed (sex, age, household size, level of education, agricultural training, years of experience in production, labor employed, size of farms, ownership, membership or not of a farmers’ organization, etc), perceptions of climate change (change in the evolution of rainfall, temperature, drought, flooding, plant diseases, violent winds, etc.), the impact of climate change on production, management strategies adaptation implemented, the constraints encountered and the adaptation strategies as well as their effectiveness. Most of the questions were of the 5-level Likert type. The collected survey data are transferred to the SPSS statistical analysis software and then evaluated by various descriptive statistical methods for this paper. In this article, to be short, we only focus our analysis on the adaptation strategies, especially the biochar technology. However, the impact and perception analysis have been developed in our other papers (articles in press). To do so, first, we presented the population characteristics before analyzing the use of biochar in the region.

Result and Discussion

Respondents characteristics

The distribution of socio-demographic characteristics of the respondents is presented in Table 4. As the results indicate, the respondents were men and women farmers. Indeed, the survey records 312 male farmers (81.3% of the sample), and 72 female farmers (18.8% of the sample). 13.8% of the farmers were under 30 years old, 27.6% of them were between 41 and 50 years old and the average age of the respondents was 44 years old. Statistical analysis of the survey results shows that 376 (97.9% of respondents) of the farmers are married against 5 (1.3%) single and 3 (0.8%) widowed. Households are made up of an average of 10 individuals and households of 10 people were the most numerous (62%). Respondents with no education had the highest prevalence in the sample 72.9% (280 farmers). In

Table 3 Overview of studies carried out and their results in Africa

Author(s)	Study area	Type of biochar	Biochar rate	Products	Principle results
Manka'abusi et al. (2019)	Burkina Faso (Ouagadougou)	Corn cob	20t/ha	Amaranth Lettuce Carrot	Improved total fresh matter yields of two cycles of amaranth by 39% and 17%, lettuce by 7%, and carrot by 11%
Häring et al. (2017)	-Burkina Faso (Ouagadougou) -Ghana (Tamale)	Husks of rice and corn cob	2 kg m^2	Vegetables	COS stocks initially doubled, but COS losses of 35% subsequently occurred. Both types of biochar did not affect soil pH, phosphorus availability, and effective cation exchange capacity (CEC), but rice husk biochar retained nitrogen (N) in the ground
Yeboah et al. (2009)	Ghana	Corn cob	3t/ha	Maiz	-Biochar resulted in 4–5% N recovery in corn shoots and roots -N recovery can be improved by applying biochar on sandy soil but not on loamy soil
Akoto-Danso et al. (2019)	Ghana (Tamale)	Rice ball	20t/ha	Lettuce	Increase in yields of 15% and 9% after 2 years.
Steiner et al. (2018)	Ghana (Tamale)	Rice ball	0.9 t to 10.7 t/ha	Lettuce	Increased lettuce yields by 93%
Rogers et al. (2017)	Tanzania (Mbeya and Songwe)	Variable	Variable	Variable	The perceived increase in crop yields from 1 metric ton per hectare to 3 metric tons per hectare, ensuring food security and increasing family income
Cornelissen et al. (2013)	Zambia	Corn cob	4t/ha	Maiz	Maize yield increases of between 80% and over 400% have been observed on biochar-amended soil compared to control soils
Kimetu et al. (2008)	Western Kenya	Corn cob	6 t C/ha	Maiz	- An increase of 2.9 tons in additional yield on soil amended with biochar compared to control plots with fertilizer but without biochar
Frü et al. (2018)	Cameroon (Nkolbisson)	Rice ball	Variable	Variable	Profit gain with net benefits of 1.44 million CFA francs and a marginal rate of return (MRR) of 33.06% compared to controls ones
Faye et al. (2021)	Senegal	Rice cob or cow manure	5–10 t/ha	Millet	-Increased yields of 100–450 kg/ha with biochar and NPK but biochar application alone did not increase millet yields - Soil pH increased from 5.5 to 6.3 and carbon from 1.84% to an average of 2.69%
Adekiya et al. (2020).	Nigeria (Owo)	Wood	0, 10, 20 to 30 t/ha	Taro	Soil characteristics and taro yield have improved

Source: author

Table 4 Frequency distribution of farmers 'sociodemographic characteristics

Characteristics	Frequency	Percentage	Mean	SD
Sex				
Male	312	81.3		
Female	72	18.8		
Age			44	12.19
Under 30	54	13.8		
31–40	124	32.3		
41–50	106	27.6		
More than 50	101	26.3		
Marital status				
Married	376	97.9		
Single	5	1.3		
Widow	3	0.8		
Household size			10	6.07
Less than 10	239	62.0		
11–20	131	34.1		
More than 20	15	3.9		
Education				
Illiterate	280	72.9		
Literate	104	27.1		
Agricultural training				
Yes	223	58.1		
No	159	41.4		
Cooperative membership				
Yes	190	49.47		
No	194	50.52		
Farm size			8	7.24
Less than 1 ha	30	7.8		
1–5 ha	142	37.0		
More than 5 ha	212	55.2		

total 27.1% (104 farmers) had a school education. As for the level of agricultural training, 58.1% of respondents compared to 41.4% declared having received training as part of the development of their agricultural activity. These agricultural pieces of training are based on the preparation of the soil, the quantity and use of fertilizers, the planting of seeds, the practice of SWC techniques, the right choice of seeds to be cultivated, the sowing periods, and even the production of biochar. The average number of years of experience of producers in agricultural activity is approximately 35 years. Most of them declare to be farmers by birth showing how experienced they are in their activities. Regarding membership in cooperatives, 50.52% of farmers were not members of any farmers' organization. Regarding farm size, 7.8% of farmers had a plot of less than 1 ha and 55.2% had a plot of more than 5 ha and the average size of farms was 8 ha.

The application of biochar and the other adaptation strategies in the Hauts-Bassins

To learn about adaptation measures, respondents were asked to indicate the strategies they were using, which are the most effective, and the constraints they were experiencing. The average scores revealed that the use of new and improved seeds, irrigation, use of chemical and organic fertilizers, the use of climate information, the SWC techniques (stone bunds, dikes, revegetation, natural regeneration, manure pit, live hedge, dead hedge, and fallow), the use of biochar, pesticide use, change in planting date, mono-cropping, crop diversity, giving up some crops cultivation, change in land size, and cultivation in lowlands are the main adaptation measures used by producers to counter climate change in the region (Table 5). Of the total sample surveyed, only 47 farmers were practicing Biochar technology as opposed to SWC which was the most implemented. Farmers in Burkina Faso still seem unaware that crop residues on their farms can be used as feedstock for biochar production. However, some farmers have combined several practices at once, which seems to have a more positive effect than practicing a single strategy. Farmers who were trying to produce biochar carried out the pyrolysis process in specially designed iron barrels, which were not well-suitable for pyrolysis. The biomasses were rather crop residues such as corn cobs, sesame stalks, corn stalks, peanut shells, sorghum stalks, millet stalks, and soybeans stalks. The quantities produced and applied were minimal. Despite this, the producers state that they have seen positive effects in terms of yields. That can mean that the biochar had some effect on the soil's quality. The constraints encountered in the production of biochar were the lack of the right materials (manufacturing materials such as barrels), the lack of biomass, the lack of workforce, and the lack of knowledge. Biochar is unknown to many farmers in Burkina Faso. The lack of knowledge is a major obstacle to any development. In light of these difficulties, the low level of use of biochar in the Hauts-Bassins and Burkina Faso, and the importance of the biochar technique for agricultural development in the war on climate change, there is an urgent need to promote the biochar technique in Burkina Faso through a popularization campaign to provide information on the practice. There is still a lot of work to be done at this level in this climate combat where all possible solutions become important. Despite what has already been done, an urgent call for commitment to large-scale projects and policies is expected.

Potential political suggestions

From these previous analyses, we can make the following recommendations starting with the promotion of climate

Table 5 Adaptation strategies and measures

Strategies and measures		*N*
1	Use of chemical fertilizer	369
2	Use of organic manure	359
3	Pulverization (use of pesticides…)	347
4	Variation of planting and harvesting dates	331
5	Diversification of production activities	327
6	Adoption of improved seeds	301
7	Modifying/reducing the size of the land	263
8	Abandonment of certain crops	222
9	Use of climate information	161
10	Stone bunds	153
11	Manure pit/composting	149
12	Maintain fallow	119
13	Dikes	113
14	Small dikes	108
15	Revegetation	102
16	Grassed strip	86
17	Only one crop cultivation	68
18	Biochar	47
19	Use of lowlands	19
20	Dead hedge	18
21	Live hedge	17
22	Use of new irrigation methods	9

and adaptation strategies education, and awareness with the aim of ensuring the effective adaptation of agriculture to climate change and ensuring a strong agri-food system:

1. All farmers must be aware of the serious consequences of climate change and must adopt adaptation strategies. To do so, farmers must first be informed. This requires the promotion and popularizing of information on the rapid progress of climate change in agriculture and the occurrence of extreme weather events.
2. Secondly, farmers should be informed about the necessity of adopting strategies to control the impacts of climate change on agriculture. This can be done by showing the positive results of adaptation practices already collected from past experiments and encouraging them to adopt sustainable agriculture practices. This comes thus to propose them practices that they can apply. Scientific research should be accelerated at this level to determine the best practices suitable for each region's climate conditions.
3. As a technology transfer, the generalization of the use of biochar technology as the case of SWC techniques must be a priority in the case of the fight against climate change in agriculture in Africa. To do so, it is necessary to: Train farmers on the production and use of Biochar and equip them with Biochar production and transport materials. In other cases, the establishment of a factory for the production and distribution of biochar to farmers is a solution.
4. In addition, a combination of improved seed varieties production, and SWC techniques with the application of Biochar is a perfect innovation for an intelligent adaptation practice to the destructive action of climate in agriculture. Not only are these types of seeds short-cycle and resistant to extremes of temperature and precipitation conditions but also SWC techniques can recover and even prevent agricultural land from degradation Biochar in turn would not only allow carbon sequestration in the soil but also fertilization of the soil and thus increase yields and decrease the release of GHG into the atmosphere.
5. The decision to adopt a method is generally linked to access to services. For example, the extension services provided to farmers by the ProSol Project in some provinces in Burkina Faso have a positive impact on the decision to adopt an adaptation strategy. So equipping farmers with the necessary materials for adaptation is of wider importance:

   -These include training on the management of the production activity, whether it will be for land management or the use of materials, seeds, and the application of techniques. Training is the basis of knowledge. During our surveys, farmers strongly recommended training for farmers.

   -Providing farmers with Biochar production materials and modern, more sophisticated, and faster production materials. One of the main problems of the farmers is the lack of production materials and access to seeds and fertilizer which are becoming more and more expensive discouraging the producers to renounce and abandon the plowed agricultural lands.
6. It would also be imperative to set up a climate change adaptation fund to encourage and motivate farmers to adopt adaptation practices. Facilitating access to agricultural credit is also a great help. Supporting them financially could well be the way to bring them to adopt this practice of biochar more. They will reap the fruits and benefits while enhancing the arable land qualities and even those that were degraded and abandoned will also become carbon reservoirs. Moreover, the application of biochar is a profitable investment in the long term.
7. It is important to facilitate access to climate information with early warning systems for farmers. When farmers are informed in advance about the status of the climate forecast, they implement practices in advance. The decision to adopt one strategy over the alternative is based on the perceived and upcoming event.

Conclusion

Climate change with its consequence of agricultural soil degradation is no longer a threat to be ignored. The impacts on agriculture in Africa are enormous. Agricultural lands in Africa are degraded and not very fertile leading to low production yields. Sustainable agriculture practices such as biochar technology have surfaced for some years now as a proven solution to this problem. Biochar's main roles are agricultural soil fertility, environmental and waste management, and soil GHG sequestration. Indeed, the effectiveness of this soil amendment has been proven by the results of most studies. However, some results show its inefficiency and its dangerousness, hence a lost cause. On the other hand, pending further scientific studies on this product, the advantages over the disadvantages and its application continues in Africa because of the positive results obtained. However, with proper adoption and implementation of biochar, guided by sound policies and good governance, biochar production has great potential to boost farmers' production and improve their quality of life. While continuing to determine the potential development of biochar, future studies might focus on the determinants of biochar implementation by farmers, on how much are the farmers willing to pay for the biochar produced in the factory and how much are they willing to spend to make their own biochar production as well.

Data Availability

The datasets analyzed during the current study are not publicly available because this is a part of the dataset for my Ph.D. thesis which I didn't finish yet and the dataset must be confidential for now but are available from the corresponding author on reasonable request.

Author Contributions Sita KONE designed and collected the primary and secondary data and managed the research content and methodology and wrote the paper. Xavier GALIEGUE approved the structure and the writing of the paper, read the paper and made corrections, and approved it for publication.

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

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