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Review

Circular Regenerative Agricultural Practices in Africa: Techniques and Their Potential for Soil Restoration and Sustainable Food Production

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Abstract: The conventional linear system of global food production and consumption is unsustainable as it is responsible for a substantial share of greenhouse gas emissions, biodiversity declines due land use change, agricultural water stress due resource-intensive water consumption patterns and land degradation. During the last decade (1994–2014), for example, the greenhouse emissions from agriculture in Africa were reported to increase at an average annual rate of between 2.9% and 3.1%, equivalent to 0.44 Gt and 0.54 Gt CO_2 per annum, respectively. Between 2000 and 2020, the greenhouse gas emissions from agrifood systems were shown to decrease in all major regions of the world, except in Africa and Asia, where they grew by 35 and 20 percent, respectively. With most of the circular agricultural practices still central to food production in the developing African countries, the continent can spearhead a global return to circular agriculture. Using a descriptive review approach, we explore the literature to examine the extent to which African agriculture is deploying these practices, the potential areas for improvement and lessons for the world in embracing sustainable food production. We underscore that the farming communities in sub-Saharan Africa have, for decades, been using some of the most effective circular agricultural principles and practices in agricultural production. We further show that practices and strategies akin to sustainable agricultural production include agronomic practices, smart irrigation options, renewable energy harvesting and waste-to-fertilizer technologies. All of these technologies, which are central to sustainable agricultural production, are not new to Africa, although they may require packaging and advocacy to reach a wider community in sub-Saharan Africa.

Keywords: circular economy; renewable resources; sustainable production; sub-Saharan Africa; sustainable soil management; soil health

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1. Introduction

Circular agriculture stems from the wider concept of the circular economy, which refers to a recovering system of agriculture in which resource inputs and waste, as well as emissions and energy leaks, are curtailed by either slowing or closing and reducing material and energy loops [1]. It is a type of circular economic model whose main principle is that all value chains operate in closed-loop systems such that materials originally intended for disposal are reused, recycled or reprocessed, leading to additional value in the economy [2]. Circular agriculture, therefore, is based on the principle of keeping products and materials in use, designing waste and pollution out of the system and regenerating natural systems for sustained production.

For an efficient circular economy, a sustainable agricultural food production system must be the central and primary sector of the economy. Communities should, therefore, transform from the traditional linear economic model that creates tremendous food waste

and greenhouse gases to a circular economic model that can reduce agriculture's waste by reusing all products and byproducts to generate additional value in a closed system. This is possible because circular agriculture is built around four main pillars, which are (a) a closed-loop waste-free agricultural production system, (b) the maximal use of renewable resources, (c) optimal resource usage and (d) the preservation and enhancement of complexity and biodiversity. These pillars define the circularity principle in agriculture [3].

With the first pillar of a closed-loop waste-free agricultural production system, this approach mimics the natural cycle of nutrient use and recycling, thereby promoting sustainability. It seeks to add to the soil through a self-nourishing ecological system that benefits the environment by transforming all waste into reusable materials such as organic manure. In this system, nutrients are recycled from waste generated along the food chain, which later is converted into organic fertilizers to produce crops or for energy recovery such as biogas. In this way, the system works by focusing on maximal nutrient use efficiency and quality rather than quantity. Ideally, there would be no more acreage or resources are used than is strictly necessary in any circular agricultural system.

Using renewable resources such as residues of agricultural biomass, food processing waste and municipal and industrial sewage sludge for additional purposes within the agricultural production system is another central principle of circularity in agriculture. Renewable resources such as the previous season's crop biomass returned to the soil, for example, will reverse or at least reduce the rate of nutrient mining, leading, in turn, to a reduction in external inputs, such as chemical fertilizers. On the other hand, crop residues may be used as feedstock for livestock, from which manure can be applied back to the soil to resupply nutrients. This will also reduce the need for external chemical fertilizers in the agricultural production system. Field leftovers such as protein-rich beetroot tops [4], fodder beets [5] or legume leaves are incorporated into livestock feedstock instead of treating them as waste. Optimal resource usage is a necessary undertaking in circular agriculture because the result is extra profits per unit input of resources. It focuses on resource optimization through the adoption of techniques such as precision farming, efficient irrigation systems and integrated nutrient and pest management. In this article, we describe the available techniques that use the principles of circularity in agriculture and discuss the various ways in which farming communities across the continent are utilizing these techniques to sustainably produce using finite resources. We highlight further opportunities and challenges regarding efforts to embrace circular agricultural principles in African agriculture and the interconnection existing between circular agricultural practices and the restoration of soil health.

A closely related approach to sustainable agricultural production is regenerative agriculture—an approach that focuses on restoring and enhancing soil health, biodiversity and ecosystem services by emphasizing practices that lead to the restoration of degraded soils, including cover cropping, crop rotation, minimal tillage and the use of organic amendments to improve the soil fertility and structure. In other words, the focus of regenerative agriculture is the overall goal of regenerating degraded land, increasing water retention, sequestering carbon and promoting overall ecological balance [6,7]. This is in a complete convergence with one of circular agriculture principles, namely the promotion of activities that lead to the recycling of all renewable resources, resulting in a reduction in the rate of nutrient mining while curtailing the need for external inputs into the soil. This, in turn, makes the two approaches of regenerative agriculture and circular agriculture complementary to one another, as the principles of regenerative agriculture, such as soil health improvement and biodiversity conservation, can be integrated into circular agriculture practices to create more sustainable and resilient food systems.

There exists scant information on how and to what extent African agriculture deploys the principles and practices of circular regenerative agriculture to sustainably produce food and reduce environmental degradation. In this review, we examine the extent, range and nature of the practices deployed in agricultural production across Africa. We explore how such practices help to sustainably use the finite resources to achieve food security and

economic sustenance among the communities involved. To achieve this, we used regenerative agriculture and circular agriculture as our inclusion criteria to generate literature that provided information about these two practices in African agriculture. The information generated was eventually organized into four main study areas, namely (i) indicators for circular regenerative agricultural practices in African food production systems, (ii) opportunities and challenges in embracing circular regenerative agricultural practices in Africa, (iii) interlinkages between circular agriculture, the circular economy and sustainable soil management in selected countries and (iv) the restoration of soil health through circular regenerative agricultural practices, with selected examples for extensification in Africa.

2. Indicators for Circular Regenerative Agricultural Practices in African Food Production Systems

Agricultural production (both crops and livestock) and the industrial processing of agriproducts are the two main aspects of the food production industry in Africa. Activities that promote circularity in agriculture are, therefore, embedded into these two production categories, i.e., farming and agroprocessing. For the farming subsector, circular agriculture practices may include those that are aimed at improving the soil fertility, practices that aim at controlling or managing pests and practices that minimize the effects on the ecosystem and the environment.

Mixed farming—a system of farming that exists where both livestock and crop production take place within the same locality and where the ownership of crops or land and livestock is integrated—is widely practiced in Africa. Mixed farming has been reported in all parts of the continent. In Ethiopia, which is second only to Uganda in terms of livestock density [8], most of the subsistence farming is mixed farming [9]. Similar practices of mixed farming practices are reported for many other parts of Africa, including Tanzania [10], Botswana [11] and South Africa [12].

Crop rotation is another common practice that enhances the soil fertility under the circular agriculture system. Crop rotation is encouraged in circular agriculture systems because of its power to enhance the soil fertility and decrease nitrogen losses [13]. Crop rotation is also known to fight weeds and prevent them from becoming dominant in a farm. This is because the variations in cultural practices that occur with each rotation tend to disrupt the life cycle of each weed species, although it also tends to create niches for a greater variety of plant species in this ecosystem. Crop rotation is practiced in many parts of Africa, most notably in sub-Saharan Africa. Cereals, especially maize, are the most dominant crop types in most crop rotation systems in Africa. The practices embraced in different countries are presented in Table 1.

Table 1. Circular agricultural practices used in different countries in sub-Saharan Africa.

S/N	Category of Practice	Name of Practice	Countries/Regions Where Commonly Practiced	References
1	Agronomic practices	Mixed farming	East Africa, West Africa, South Africa	[14]
			Horn of Africa (Ethiopia)	[9]
		Crop rotation	Nigeria, Malawi, Zimbabwe, Ghana, Cameroon, Kenya, Benin, Burkina Faso, Mozambique, South Africa	[15–17]
		Agroforestry	Tanzania, Kenya, Uganda, Ethiopia, Malawi, Madagascar, Nigeria, Ghana, Niger, Zambia, Zimbabwe, Burkina Faso, Mali, Senegal, Burundi, Rwanda	[18–20]
		Certified organic agriculture	Tanzania, Burundi, Kenya, Egypt, South Africa, Ethiopia, Tunisia, Sierra Leone, Congo, Burkina Faso	[21,22]

Table 1. *Cont.*

S/N	Category of Practice	Name of Practice	Countries/Regions Where Commonly Practiced	References
2	Renewable energy harvest and use practices	Solar power	Mali, Gambia, Burkina Faso, Niger, Senegal, Kenya, Ghana, Tanzania	[23–26]
		Bioenergy for agriculture	Kenya, Tanzania, Ethiopia, Uganda	[27,28]
3	Smart irrigation options	Rainwater harvesting	East Africa (Kenya, Uganda, Tanzania); West Africa (Mali and Ghana); and South Africa	[29–31]
		Wastewater recycling/sewage sludge	North Africa (Tunisia, Egypt)	[32,33]
			South Africa	[33,34]
4	Waste into fertilizer	Composting	West Africa, East Africa, South Africa	[35–39]
		Manure from livestock	West Africa, East Africa, South Africa	[40,41]

Agroforestry is practiced in sub-Saharan Africa (SSA) in a variety of combinations, including (a) sequential agroforestry, a practice in which trees and crops are grown in rotation; (b) relay fallow agroforestry, characterized by fast-growing, nitrogen-fixing leguminous shrubs planted in a time-sensitive staggered arrangement with target annual crops; or (c) tree–crop intercropping, a practice in which crops and trees are planted simultaneously under varied spatial arrangements [19]. Consequently, there are at least eight major agroforestry practices/technologies dominant in SSA agriculture (Table 2).

Table 2. Major agroforestry practices used in SSA countries.

Agroforestry Practice/Technology	Region/Country Most Reported/Documented	Functional Role in Circular Agriculture			Selected References
		Food/Fuel Production	Nutrient Cycling	Other Ecosystem Functions	
Relay and mixed intercropping	East Africa, Tanzania, Uganda, Malawi	√	√		[42,43]
Terracing agroforestry	East Africa, South Africa, West Africa—Morroco	√	√	√	[44,45]
Home garden agroforestry	North East and Horn of Africa, South Africa, West Africa, East Africa	√	√	√	[46–49]
Shrub/fertility tree agroforestry	South Africa, East Africa		√	√	[50–52]
Silvopastoral agroforestry	East Africa, South Africa, North and Horn of Africa	√		√	[53]
Taungya system	East Africa, West Africa, South Africa	√		√	[54]

Mixed cropping is one of the most common practices in SSA agriculture. It involves growing two or more crop species (or cultivars) simultaneously on the same piece of land in a variable order (with or without definite rows), providing advantages such as pest and disease control, increased productivity and food security [55,56]. Where the different crops are established following a strict pattern or arrangement, this practice is referred to as intercropping. Recent studies have shown that mixed systems result in higher yields than pure stands because a companion crop usually grows better in scenarios in which the weather conditions do not favor one crop. On the other hand, the agroecosystem services provided by mixed cropping systems include potential reductions in pest outbreaks, in

addition to increasing the biodiversity of beneficial organisms such as soil microorganisms and insects [56].

Figure 1 above depicts a mixed cropping system, commonly practiced in Tanzania, consisting of two or more nitrogen-fixing crops. Groundnuts and pigeon peas are used to improve the soil's fertility status and as cover cropping (groundnuts) that helps to keep the perennial crop (cashew nut trees, in this case) clear of weeds and reduce the threat of wildfires.



Figure 1. Example of mixed cropping practice involving one perennial tree crop—cashew nuts—and two annual legumes—groundnuts and pigeon peas—in Southern Tanzania. (Photo by Hamsi J. Tindwa, Sokoine University of Agriculture).

Bioenergy is any form of energy from biomass materials and it ranges from solid primary energy (fire wood, charcoal and combustible waste) and gases (biogas and biohydrogen) to liquid fuels (bioethanol and bioenergy) [27]. Some forms of bioenergy, such as biogas or liquid biofuels, can be directly applied to aid agricultural production. The use of biogas as fuel for farmstead cooking and steam production to aid electricity generation has been documented in several parts of sub-Saharan Africa, including Kenya [57] and Zimbabwe [58]. In 2017, for example, a commercial vegetable and flower farm in Naivasha, Kenya was reported to be the first in Africa to generate electricity from biogas and connect the surplus to the national grid, thereby contributing to efforts to reduce carbon emissions from oil-powered generation [58,59]. A different study by Söderberg [60] has documented the high potential for electricity generation from biogas digestion plants scattered across the country, which could contribute to the national electricity grid.

Kenya also possesses the first agrovoltaic system, which helps to harvest solar energy for the farm; here, solar panels are constructed that are several meters high, with gaps between them so that crops can still be grown underneath, while generating electricity

for the farm [22]. Similar interventions in which solar energy is harvested to power farm activities are reported in Niger [61], Nigeria and Tanzania [62].

Statistics show that over 600 million people in Africa live without access to electricity, although a significant number of them can still be served by cheap electricity generated at farm gates in various parts of the continent. There exists great potential for commercial biogas generation to both feed poor national grids and power farming infrastructure. Farms with biogas generation capabilities can, therefore, increase their incomes and productivity by generating biogas and distributing the surplus commercially [63]. The use of biogas as an alternative power source has been shown to mitigate the impacts of using fossil fuels to generate power in South Africa [64]. The identified critical barriers to commercial biogas development and production across the continent include high initial capital costs, weak environmental policies, poor institutional frameworks, poor infrastructure and a general lack of willpower to implement renewable energy policies and set challenging targets [63].

Smart irrigation practices have been reported to carry the potential to double food production in Africa. An analysis of the best practices from Ethiopia, Kenya, Mali, Morocco, Niger and South Africa showed that irrigation can double crop yields compared to rain-fed agriculture [31]. Although only about 6 percent of the cultivated land is currently irrigated in Africa, the irrigated land in SSA could be expanded from the current 7.7 to 38 million ha, compared to the total potential of over 47 million ha [30]. A report has described experiments on bundled "smart irrigation" technology that included improved vegetable varieties (tomatoes and sweet pepper), an automated irrigation kit and a low-cost screen house in the Babati area of Northern Tanzania, which resulted in 35% higher marketable yields, 25% higher gross returns, 35% labor savings, reduced soil erosion and water savings [29].

Rainwater harvesting in agricultural farms has been in practice in a number of countries in Africa, mainly to either support irrigation programs or to supplement household and industrial needs at a community or family level. Rainwater harvesting has been shown to offer both benefits/opportunities and challenges to communities, although the opportunities outweigh the challenges, especially in the semi-arid lands of Africa. Indigenous rainwater harvesting techniques, for example, have been shown to increase the water content in the root zone, and the appropriate design can diminish crop water stress in semi-arid areas of Africa [65]. Since its introduction in parts of Africa, such as Kenya and Tanzania, by non-governmental organizations such as the UN, rainwater harvesting has proven fundamental in raising crop productivity from 1 to 3–4 tons per hectare [66].

Composting, as a means of waste-to-fertilizer conversion, is practiced in several SSA countries. In one study, for example, optimized composting enabled the replenishment of soil nutrients and increased the capacity of soils to store plant-available nutrients and water in degraded banana-coffee-based farming systems in Tanzania [67]. A study that compared manure management practices on small, medium and large-scale farms in Ethiopia and Malawi confirmed the potential of manure to improve crop yields and promote sustainable agriculture in SSA, as well as highlighting that efforts to improve manure management in SSA should strengthen the enforcement of existing policies and provide an enabling environment for the adoption of good manure management practices [40].

A study in Tunisia reported that the combined application of municipal solid waste compost (MSWC), sewage sludge compost (SSC) and farmyard manure (FYM) increased the organic matter, cation exchange capacity and available P, Ca, Mg and K in the soil, as well as the grain yield (up to 51%) and the overall nutrient content of barley plants [68]. Similarly, the combined application of crop compost and FYM has been shown to improve the soil quality parameters in selected maize and cassava agroecosystems in Tanzania [69]. Research also shows that as farms intensify and become smaller through intergenerational subdivision, as is the case in communities living in the highlands of East and Central Africa, where population densities of up to 800 persons per square kilometer are becoming common [70], the need to enhance nutrient turnover is increased. This is because the soil fertility status declines sharply, presenting a serious threat to food security. In such

circumstances, combining compost with liquid manure has been reported to produce better results than either of the two when applied alone, in terms of improvements in the soil structure, soil fertility, crop growth and vigor, leaf color intensity and maize yields [71]. On the other hand, promising results have been reported when farm yard manure has been combined with a reduced dose of mineral fertilizer. A study in Ethiopia showed that the combined application of FYM with half of the recommended mineral nitrogen and phosphorus fertilizer increased the grain yield of the crop by 185 and 170%, respectively, over the control treatment [72]. A different study by Laub et al. [73] concluded that, at realistic application rates, the maize yield is best sustained by the combined application of farmyard manure and mineral N in integrated soil fertility management.

3. Opportunities and Challenges in Embracing Circular Regenerative Agricultural Practices in Africa

Circular agriculture has three key principles, namely (a) preserving and enhancing natural resources, (b) the efficient use of resources and (c) multipurpose use and recovery from waste. Each of these areas offers unique opportunities for both farmers and communities to further the concept of circularity in agricultural production. This is because each of these key principles has been involved in an interplay with agricultural production systems in SSA for generations. The region now requires the coordinated harnessing of emerging technologies that offer more opportunities for agricultural production, manufacturing and waste management, so as to improve livelihoods and achieve poverty reduction in SSA.

A World Bank report estimates that, with its fast-growing population, waste generation in the SSA is expected to triple by the year 2050 [74]. Since SSA is characterized by middle- to low-income countries, the proportion of organic waste in the overall amount of municipal waste is relatively higher than in more developed regions of the world. SSA currently produces around 54 and 56% of all food and green waste, respectively, compared to only about 32% of the total waste produced in high-income countries and cities [74,75]. This highlights the great potential of the third principle of agricultural circularity—multipurpose use and recovery from waste. Most of the organic fraction of waste can be converted to fertilizer using affordable technology. Instead of burying such waste in landfills or subjecting it into open burning or dumping, the authorities should seize the opportunity and the potential for its conversion into organic fertilizer using simple technologies such as composting. One study in Arusha, Tanzania reported that the energy contained in municipal solid waste generated in Arusha was equivalent to about 30% and 67% of the energy contained in coal and pure biomass [76]. The utilization of energy in the form of heat, electricity or steam can lead to better energy recovery and protect the environment from toxic emissions. A recent study that aimed at evaluating four prospective waste-to-energy options, namely incineration, anaerobic digestion, gasification and landfill gas, found that producing 200 MW of energy using biogas cost 36% less, potentially resulting in monthly savings of USD 5.46 million for Ghana. This highlights anaerobic digestion as a superior option, offering renewable energy production, valuable bio-product creation and a comparatively lower greenhouse gas emission effect [77]. This is an exemplary option that other cities across SSA could invest in to achieve circularity in agriculture.

One of the greatest challenges facing most SSA countries is the prevailing practice of generating and accumulating heterogeneous waste and disposing of it in designated areas without prior segregation according to the type of waste [77,78]. This is an unsustainable practice that makes it difficult to implement any of the waste management options mentioned above. Another challenge in the use of biomass to develop sustainable bioenergy is the absence of a clearly documented or traceable biomass value chain that would ensure a constant supply of biomass to fuel energy production machinery in most SSA countries.

Apart from the problems associated with the absence of waste separation schemes, and hence inappropriate waste disposal, other challenges impeding the waste-to-energy approach in most of SSA include ineffective waste collection methods, a lack of suitable waste-to-Energy (WtE) generation technology in place, a lack of financial support and

policies related to WtE projects/interventions and the absence of coordination between different governmental institutions [75].

Furthermore, as the cities in this region grow into higher-income communities, the dynamics of waste production are expected to change, from higher proportions of food and green (biodegradable) waste to more solid dry waste that could be recycled, including plastic, paper, cardboard, metal and glass [75]. Although this presents another potential challenge, especially regarding the available waste management options, the choice of an appropriate waste management option is significant, as not all technologically supported options, such as incineration or open dumping without gas-capturing mechanisms in landfills, are compatible with the principles of circularity. Waste-to energy investments present the best opportunities for developing nations. This is because, in addition to reducing greenhouse emissions, such investments are anticipated to create employment opportunities for the surrounding communities [79].

The countries in SSA can also work to fulfill the goals of the second principle of circularity in agriculture—the efficient use of resources. Instead of clearing more land for agricultural production, producers and governments can invest in projects that help to reduce food losses. This can largely be achieved through investing in improving the quality of and access to storage facilities and efficient transport systems. There are a few reports on efforts in various SSA countries to address food loses and improve the use of renewable resources. Examples of such initiatives are Taimba, a Nairobi-based agri-tech initiative that consists of a mobile-based cashless platform that connects farmers to retailers, and Twiga, which is a Kenyan business-to-business (B2B) food distribution platform. Both of these use technology to provide efficient delivery while reducing the loss of food supplies.

4. Interlinkages Between Circular Agriculture, the Circular Economy and Sustainable Soil Management in Selected Countries

The circular economy is an economic development model designed to promote all practices that lead to extracting the maximum value from finite resources through extending their lifetimes, while protecting and improving the environment, advancing economic development and job creation, bolstering the roles of women and providing opportunities for youth [80]. If well implemented, it should replace the linear, conceptually unsustainable "take–make–waste" economic model that dominates economic activities and global supply chains. To achieve circularity in the economy, there must be sustainable resource management such that finite resources are carefully managed, avoiding their depletion and maximizing products' use potential as we reuse, recycle and refurbish them. In other words, the circular economy aims at decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles [81].

According to the definition put forward by the Ellen MacArthur Foundation [2], the circularity of the economy revolves around three main pillars: (a) eliminating waste and pollution, (b) circulating products and materials (at their highest value) and (c) regenerating nature. Regarding the first pillar of eliminating waste and pollution, the economy needs to be propelled towards the use of renewable energy and materials so that economic activities are decoupled from the indiscriminate consumption of finite resources [2]. This can be implemented at the production, processing/manufacturing or consumption stage of the product chain. The elimination of waste and pollution requires that we redesign all economic activities by providing an onward path after they have been used. Thus, everyday commodities must be designed in such a way that they can either be reused or recycled as other useful products, effectively returning them to useful ends. Over time, and if conducted correctly, this means that waste will not accumulate in the environment.

A direct linkage to agriculture lies in the principle of circulating products and materials at their highest value, with the goal of keeping materials in use either as products or as components and feedstock for other products after their initial use. In this way, food remains of agricultural origin and other greens could be processed into animal feed, hence effectively circulating the same materials from one product to another. In line with this

concept, a start-up company in Tanzania, called Afri-EcoFeeds, works to process up to 50,000 megatons of food waste peels and trimmings and produce about 1000 megatons of animal feed per year, serving about 2000 animal farmers in the Manyara and Arusha regions of Tanzania [82]. Similarly, a local company in Tanzania called Chanzi purchases unwanted food waste from smallholder farmers, commercial farms, urban markets and businesses to convert them into protein-rich animal feed additives using black soldier fly larvae. It then sells the feed additives to livestock, poultry and fish farmers; agro-dealers; and feed mills across Tanzania and Kenya [83]. A similar company in Uganda (Ugavoil), in partnership with the Kasese Municipal Council, uses black soldier flies to convert organic waste collected from various points around the Kasese Municipality to produce both organic farm inputs and animal feed [84].

5. Restoration of Soil Health through Circular Regenerative Agricultural Practices: Selected Examples for Extensification in Africa

The soil is known to provide multiple ecosystem services, leading to the sustainable functioning of the ecosystem, which directly affects human health and agricultural productivity [85]. As a substrate for plant growth, the soil is essential in sustaining plant vigor and growth and in the regulation of water dynamics and carbon sequestration [86], all of which contribute to a healthy soil ecosystem. In other words, healthy soil is the result of an interconnected web of activities involving soil organisms and organic matter as they are modified by agronomic practices. Healthy soil must have the capacity to provide an environment for the optimum growth and development of plants and thus support the health of animals and humans. Therefore, the circular regenerative agricultural practices summarized in Figure 2 can invariably be used to positively moderate and modify the soil content and its potential for the emission of toxic greenhouse gases into the atmosphere [87].

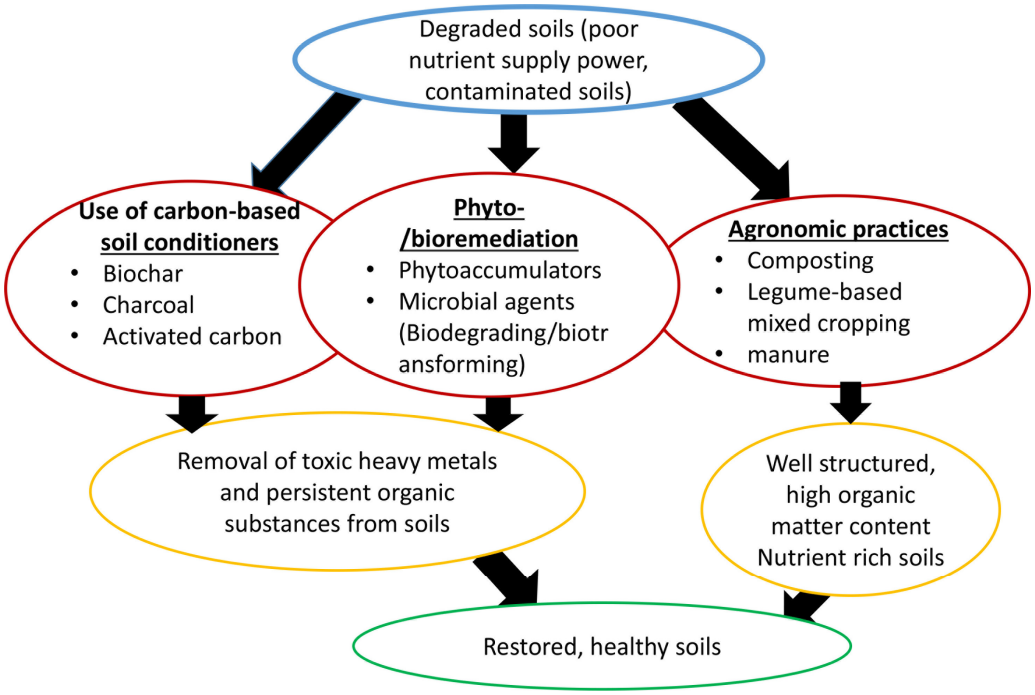


Figure 2. Summary of circular regenerative agricultural practices used to restore soil health in degraded soils in African agriculture. Red cycles show the alternative regenerative agricultural practices that can be applied on degraded soils, yellow cycles show the possible results of the practices leading to restoration of soil health- green cycles.

Composting is one practice that employs circular agricultural principles to restore soil health. This act of transforming organic matter, including food waste, kitchen scraps and agricultural residues, into nutrient-rich compost is a powerful tool to replenish soil

fertility. Composting, for example, was shown to be a good option for the conversion of biowaste into high-agronomic-value organic fertilizer with a high C/N ratio and other plant nutrients in São Tomé and Principe [88]. A study in Burkina Faso showed that the application of compost produced from selected household refuse, animal manure, crop residues and ash helped to improve the soil quality by raising the soil's cation exchange capacity (CEC) and overall nutrient content, compared to soil that received no compost [89].

The intercropping of cereals and legumes—a circular agricultural practice known to improve the soil quality and productivity—is practiced in most SSA countries. Mbili-mbili, a form of intercropping in which two rows of a cereal are intercropped with two rows of a legume, was shown to result in high net revenues for farmers, in addition to improving the overall soil fertility status [90].

Similarly, animal manure addition to farm soils has been practiced with considerable success in improving soil health in some countries in SSA. Studies in Nigeria have proven that the addition of manure to soils can result in improved chemical and physical properties of the soil, in addition to improving the grain yields of crops such as maize [91–94]. The successful use of animal manure to boost soil health parameters and consequently crop yields has been reported in Tanzania [95], Ethiopia and Malawi [40].

The use of soil conditioners to help to decontaminate soils with toxic substances has been reported to successfully reduce the contamination levels and improve the overall health of soils. Biochar, for example, was shown to be extremely effective in the remediation of heavy-metal-contaminated alkaline and acidic soils as compared to charcoal or activated carbon [96]. In another study, biochar has been reported for its potential to enhance the soil and crop productivity through enhanced nutrient and soil moisture availability, the amelioration of acidic soils and the stimulation of microbial diversity and activity in a number of African countries [97,98]. On the other hand, calabash was shown to surpass five other phytoremediator plants in the removal of DDT from contaminated soil by phytoaccumulation [99]. A number of other studies have reported attempts to use phytoaccumulator plants to restore the health of contaminated soils in various parts of the African content [100]. Similarly, several studies have shown the potential of legumes to restore the health of degraded soils by improving their organic matter content and nitrogen fixation [100,101].

6. Conclusions and Recommendations for the Future of Africa's Circular Agricultural Systems

Circular agriculture, as discussed in this paper, is a model that minimizes the amount of external inputs for agricultural production and closes nutrient loops while reducing the negative impacts on the environment through eliminating unwarranted waste discharges. Recently, sustainability has become a global priority, and the stakes for sustainable transformation in agriculture are particularly high in Africa. The circular agricultural principles and practices discussed in this paper carry the potential to transform sub-Saharan African agriculture and enable farmers to achieve sustainable production.

The future of African circular agricultural systems is, however, dependent on the development and placement of supportive infrastructure, including nationally governed programs aimed at equipping the agricultural sector with tools and innovative means of applying circular regenerative agricultural principles in production. Educating the farming community about the circular agricultural practices that represent the best approach in migrating to a circular economy could lead to the creation of a sustainable and more inclusive economy.

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