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Can Sustainable Agricultural Innovations and Tools be a Solution to Africa's Food and Environmental Challenges? A Review

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Abstract

Sustainable agricultural innovations are crucial to boost food quality and quantity needed to feed Africa's doubling population (PopulationPyramid.net) faced with complex challenges such as climate change, biodiversity conservation, emerging diseases, urbanization pressures, etc. These challenges hinder the successful implementation of Africa's agenda 2063 agricultural development plan and necessitated an urgent need for the development of sustainable innovative farming systems and tools to overcome these challenges. This resulted to the development of agroecological practices, PUSH-PULL technology by INCIPE, and LANDPKS mobile app technology by ATPS.

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This paper reviews 7 sustainable innovations in Africa helping to improve crop production, analyses their advantages and constraints, potential of each to be fully integrated in the continent's agriculture system by 2063, and classifies them according to efficiency using the Hill and MacRae analytical framework. Only soil nutrient management techniques were averagely integrated into actual agriculture of the African continent while LandPKS, Push-Pull, and the other agroecological innovations were not well integrated in the continent. The paper also highlights some measures to facilitate expansion and deployment of these innovations and recommends quantification of SOC and GHG emission from the innovations should be simulated to 2063 to aid choice of innovation.

Keywords: climate change; food security; Soil Organic Carbon; Sustainable agricultural innovations; yield.

1. Introduction

Africa's population a decade ago was twice as much as that of 1980 [1] and this geometric increase in population is expected in the next three decades increasing from about 1,340 million in 2019 to about 2,489 million in 2050 [2]. This steady increase in Africa's population is expected to contribute greatly to the forecasted increase in world's population from the present 7-8 billion to about 10 billion people in 2050 [3]. This growth in population will consequently generate an increase in the demand of food to feed the growing population. Africa's agricultural production which is generally attained through cultivation of more land by a larger labor force has been on a steady rise, almost tripling, with very little development in factors of production and in yields [1]. Consequently, the United Nations and World Health Organization made a call suggesting that food production be doubled by 2050 [3]. This call is in line with the Africa's Agenda 2063 goal of embracing modern agriculture for increase productivity and production. The Africa's agenda 2063 is guided by Sustainable Development Goals (SDGs) and largely dependent on agriculture for its success amidst complex challenges such as climate change, emerging diseases, pressures on biodiversity conservation and water supplies, and shifting market demands of the growing human population. Thus, Africa's agriculture is seriously challenged in responding to UN call of doubling food production and attaining Agenda 2063. However, UN SDG 2 and Africa's Agenda 63 goal 5 calls on the promotion of sustainable agricultural innovations as a bridge of the gap between food security and improved nutrition and protection of the environment amidst these challenges. Agenda 2063 therefore recognizes that sustainable agriculture contributes to; conservation and sustainable use of oceans, water resources, energy resources, maintaining forest and forest ecological services, ecosystem health, addressing climate challenges, halt biodiversity loss, and combatting land degradation and desertification in Africa [4]. Sustainable agriculture is therefore the means of achieving food production through environmentally friendly, socially fair, and economically beneficial technological innovations. Sustainable agricultural innovations therefore contribute to sustaining the livelihoods of millions of people around the world, and particularly in Africa. As a consequence, there is an increasing demand for the production of larger food quantities and the achievement of sustainable development. The concept of sustainable agricultural innovations as indirectly or indirectly linked to the achievement of many Sustainable Development Goals (SDGs) is a demonstration of the fact that sustainable agricultural innovations have been at, the focus of many international attention and efforts for several decades. This has led to growing international recognition of sustainable agricultural innovations as a top priority in national plans if the world is to archive food security for present and future generations. The African union is not left and as such sustainable agriculture is linked to the achievement of many of the goals of the African Union's Agenda 2063. The AU Agenda 2063: "The Africa We Want", is a remarkable plan of action to consolidate and position Africa's priorities and concerns in the SDGs. It underscores the interconnectivity between people, the planet and the economy as it aims for prosperity and well-being, for unity and integration, with freedom from conflict and improved human security. The Agenda 2063 is aspirational in outlook, requires country-specific actions some of which are hinged on sustainable agriculture, encouraging their integration and mainstreaming into core policy areas [4]. Authors in [5] indicated that the most appropriate agricultural innovations to attain the goal of higher and sustainable food production around the world was strongly being debated in a contrasting manner. Most interventions on crop production in Cameroon and elsewhere in most of Africa emphasizes on high yields with little concern on how to sustain farmlands for future benefits [6]. For example, the Ministry of Agriculture and Rural Development in Cameroon is focused on improving yields through dissemination of farm tools, yield enhancing seeds, and agribusiness awareness campaign, with little attention on sustainable farm land management. In Africa, most agricultural options range from highly mechanized technologies to ecological farming practices. Highly mechanized farming with genetically modified seeds including application of agrochemical fertilizer, and pesticides could help match the future food demand but with far reaching consequences on the environment [7, 8]. On the other hand, the author in [9] highlighted some sustainable agricultural innovations such as natural biological control of pests, no or reduced tillage, and crop residue management that increase soil biota activity and improve soil fertility, as possible options of farming with minimal environmental effects. Also, the author in [10] highlighted some old and widely used agricultural practices in the world especially practiced in developing countries including Africa such as organic soil fertilization, crop rotations, mixed cropping, residue management or biological pest control. However, in the past 20 years, these practices have been increasingly considered as sustainable agricultural innovation [10]. Sustainable agricultural development has become an issue in national and international agenda. According to [11], sustainable agricultural development is "the management and conservation of natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. FAO has also encouraged blueprints emphasizing a balance between environmental wellbeing with productivity exploitation in both developed and developing countries. Some examples of such sustainable agriculture innovations in the context of developing countries considered in this review are: use of LandPKS mobile app tool, Push-Pull technology, and other agroecological practices including; irrigation, minimum tillage and intercropping with legumes, crop rotation, agroforestry with timber and fruit trees, residue management, and use of organic manure. However, there are still some lapses in specifying the characteristics that identify them as sustainable innovation practices. Also, the benefits and constrains, plus the potentials of each sustainable innovation in overcoming Africa's food and environmental challenges need to be clearly specified. Furthermore, the recent innovations such as push-pull technology and LandPKS app with promising characters for African Agriculture and the agroecological practices need to be evaluated in other to identify the best innovation to be deployed. An innovative practice can be something completely new, or a practice based on age-old principles or techniques that have been studied less and are newly adapted, thus creating a novelty for improvement [12]. So far, these sustainable innovations have been published in various books and journals some having detailed literature on just one or some of the practices or giving just a description of the practices without detailing the criteria to qualify them as such. Also, a summarized evaluation of the potential of sustainable agricultural innovations in Africa has, to our knowledge, not yet been reviewed. The aim of this review therefore, is to identify, evaluate and present sustainable agricultural innovations together with their potentials, benefits and constrains in tackling Africa's developmental challenges of food production to feed the growing population and climate change. In this paper, we identify sustainable cropping innovations of crop-based farming systems in tropical Africa, analyzing them base on diversification of systems and their potentials and constraints, and classifying them into efficiency of increase, substitution, and redesign. In addition, we analyze the ability of recently developed sustainable agricultural innovations to contribute to food production and fight against environmental degradation in Africa thereby fostering development and to assure economic viability for farmers.

2. Sustainable Agricultural Innovations (SAIs)

SAIs are environmentally non-degrading, resource conserving, socially acceptable, technically appropriate, and economically viable techniques applied in food production [13]. According to the author in [14], agricultural sustainability innovations could focus on improving genotype through the full range of modern biological approaches, as well as improved understanding of the benefits of ecological and agronomic management, manipulation and redesign. Conventional agriculture is the cause of market failures of agricultural products through the negative impacts as arising from overuse of natural resources as inputs or their use as a sink for pollution. Reduction in synthetic inputs in agricultural systems minimizes the negative impacts on the environment and social sector (Figure 1). Adoption and use of SAIs such as reduced or no tillage, residue management, and organic fertilizers will enhance retention of soil organic matter and reduced risk of soil erosion thereby contributing to increase in crop production [15]. Other SAIs for instance intercropping, crop rotation, push-pull technology and other integrated pest management (IPM) systems disrupts pest cycle and reduces pest outbreaks thereby enhances crop protection, hence increase yields [16]. SAIs are clearly offering multipurpose benefits while simultaneously promoting productivity and sustainability (Figure 1).

The author in [17] highlighted the main principles of SAIs to include: (i) integration of biological and ecological processes including nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation, and parasitism into food production processes; (ii) minimize the use of non-renewable inputs that cause harm to the humans and the environment ; (iii) make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs; and (iv) make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest and credit management. The following are descriptions of some identified SAIs practiced in Africa;

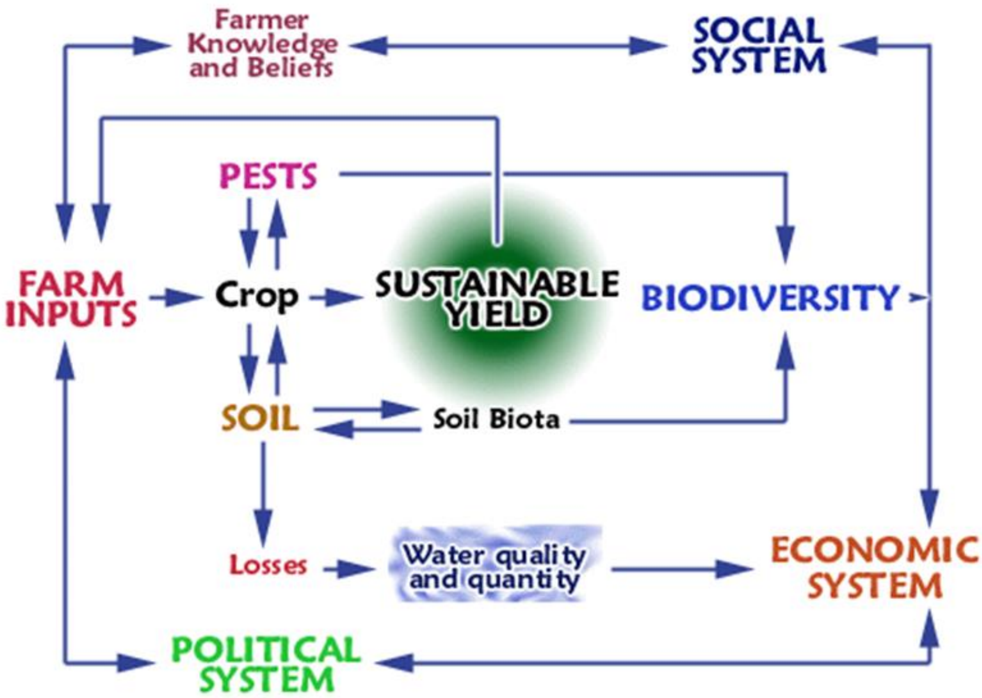

Figure 1: Holistic nature of sustainable agricultural Innovation

2.1. Land Potential Knowledge System (LandPKS)

The Land Potential Knowledge System (LandPKS) Mobile Technology for Agricultural Productivity and Resilience is an innovation of African Technological Policy Studies (ATPS) Network in collaboration with United States Department of Agriculture-Agricultural Research Studies (USDA-ARS) seeking to produce a set of innovative mobile data collection and analysis tools to support land management at local levels and land use planning for optimum food production, land restoration, climate change adaptation, and biodiversity conservation programs [18]. The main purpose is to globalize knowledge by collecting, sharing and integrating local and scientific knowledge about the potential productivity and resilience of lands in order to support long-term sustainable land productivity [18]. According to [18], the LandPKS project was conceived to: (i) directly support land management decisions by farmers, ranchers, and pastoralists. (ii) inform land use planning and investments in land management by governments, non-governmental and overseas development assistant organizations. When knowledge on land potentials is shared by various stakeholders such as governments, farmers, pastoralists, and development workers through LandPKS then they will be a sustainable increase in agricultural production, rangeland restoration and other ecosystem services. With the advent of digital revolution, efforts have been on the rise to modernize and globalize agricultural knowledge which eventually gave birth to LandPKS suite of mobile apps in agriculture. LandPKS is therefore useful at all levels of the community as stated by author in [18]: (i) At the global level, the LandPKS technology aims to facilitate the development of knowledge system and make real-time information about crops, soil types, and land use strategies accessible for decision making in agricultural production. (ii) At the regional level, the LandPKS system can be used to inform land use planning at a finer scale than is possible with generalized soil maps. (ii)

At the national level, governments, NGO's and donor agencies can use the system to help identify where support (development projects) for conservation, production type and other development efforts are likely to have the greatest impact, and avoid mistakes that sometimes increase, rather than reduce, land degradation. Furthermore, policymakers will be able to aggregate data across larger areas without losing key information, such as the presence of small, highly productive, bio-diverse, or vulnerable sites within a region. (iv) At the Local level (farm/conservancy/watershed), farmers, extension agents, development planners, and consultants can use the system to supplement their own knowledge of land potential and answer questions about sustainable land management options at the field scale. LandPKS provides agriculture extension workers with the ability to instantaneously access the best available information and interpret it in the context of local socio-economic conditions and local values, including crop preferences for a particular farm location.

2.2. Push-Pull Technology (An Integrated Pest Management Innovation)

The author in [19] defined integrated pest management (IPM) as a strategy applied to prevent and overpower or eliminate pests with negligeable impact on human health, the environment and other organisms. It is a management innovation that encourages the use of natural and cultural pest control practices which anticipates and manage pest problems and populations to reduce crop losses [19]. Even though IPM takes more time and needs close monitoring than simply pesticides application. Its advantages to farmers and the environment are numerous. Some of the IPM techniques to reduce and control pests include, modifying habitat, improving soil health, using resistant plant varieties, use of pest predator, and push-pull technology. In this review, focus is on the push-pull technology as an IPM innovation. Push–pull technology is an IPM innovative cropping system that was developed by the Kenyan International Centre of Insect Physiology and Ecology (ICIPE) in partnership with UK's Rothamsted Research Centre, Kenyan Agricultural Research Institute (KARI) and other Kenyan local partners working on integrated pest, weed and soil management in cereal–livestock-based farming systems [16] This technique involves attracting stemborers with Napier (Pennisetum purpureum) or Bracharia (Mulato II) grass, planted on the border of the field as a trap plant (pull), while driving them away from the main crop using a repellent intercrop (push) such as desmodium forage legumes (Desmodium spp.). Chemicals released by desmodium roots stimulates germination of the parasitic striga weed, but then prevent them from attaching successfully to maize roots. The striga eventually dies and the number of seeds in the soil is also reduced [16]. Milk production is also facilitated in this technology as a way to diversify farmers income by using the accompanying plants (Napier or Bracharia grasses and desmodium) as high-value animal fodder. Furthermore, besides being a good ground cover, desmodium is a nitrogen-fixing legume that improves soil fertility and minimizes soil degradation. Consequently, the push-pull technology effectively addresses major production constraints, and is economical as it deals with locally available plants without expensive external inputs. This SAI involves the use of locally available plants as perennial intercrops and trap crops in a mixed cropping system that fits well with African traditional mixed cropping systems and is therefore appropriate for smallholder farmers in Africa [16]. Push–pull technology is built from the fundamental principles of chemical ecology, agrobiodiversity, and plant–plant and insect–plant interactions. According to authors in [20] description of the push-pull technology, the main cereal crop is planted with an intercrop, desmodium (either silverleaf: Desmodium Uncinatum, or Greenleaf: Desmodium Intortum) (figure 2) which repels stemborer moths (push) and simultaneously attracts their natural enemies. The desmodium intercrop releases root exudate allelochemicals that induce poor miserable germination of striga seeds, thus drastically reduces the striga seeds and hence very effective control of this harmful weed [16]. Secondary metabolites with striga seed germination stimulatory and post-germination inhibitory activities are present in the root exudates of Desmodium Incinatum, which directly interferes with parasitism [16, 22]. This combination therefore provides a new approach to in situ reduction of the striga seeds in soil through poor and miserable germination, even in the presence of cereal hosts in the vicinity [16, 22]. The authors in [16] further highlighted that other Desmodium spp. have also been evaluated and showed similar effects on striga [23]; these have been incorporated as intercrops in maize [24], sorghum [23], millet [25] and rice [26]. The companion crops, Napier grass or Bracharia and desmodium, are valuable themselves as high-quality animal fodder. The attractant trap plant, Napier or Bracharia grass (pull), planted as a border crop around the intercrop (Figure 2) to simultaneously attract the gravid female stemborer (usually laying eggs and attacking the maize plants) being repelled from the maize plant due to the presence of desmodium [27]. The behavior-modifying stimuli release by companion plants manipulates the abundance and distribution of stemborers and beneficial insects for better management of the pests [28]. The trap crop plants produce more of the green leaf volatile chemical signals (E-b-ocimene and E-4,8-dimethyl-1,3,7 nonatriene, semiochemicals), used by gravid stemborer females to locate host plants than maize [29, 30].

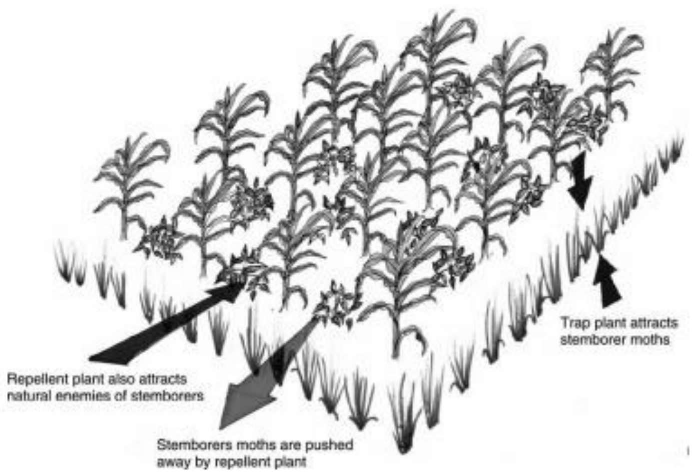

Figure 2: How the push–pull technology works. Source: [16].

About a decade ago, the push-pull technology has been adopted and used by over 30,000 farmers in the East Africa with relatively small resources and has shown to be very appropriate for smallholder farmers who do not purchase seasonal inputs [16]. These smallholder farmers saw tremendous increase in maize and sorghum grain yields with minimal inputs from below 1t/ha to about 3.5t/ha and 2t/ha, respectively [21] as a result of the effective control of stemborers, striga weeds, and improved soil fertility [16]. Also, overall soil health saw improvement resulting from nitrogen fixation by desmodium (110kg N/ha), increased soil organic matter and soil moisture conservation [16]. Furthermore, in terms of ecology, push-pull technology has improved soil biodiversity, thus further improving soil health and fertility [16]. Additionally, because desmodium provides ground cover, it leads to reduced soil temperatures and, together with surrounding Napier grass, protects the soil against erosion. Therefore push–pull farms are sustainable and resilient, with improved potential to mitigate the effects of climate change [16]. Both Desmodium, Bracharia, and Napier grass, grow perennially and provide valuable year-round quality animal fodder leading to increase milk production whereas the sale of desmodium and bracharia seeds generates additional income for the small holder farmers [21]. The push–pull technology has thus opened up significant opportunities for smallholder farmers growth and represents a platform technology around which new income generation and human nutritional components, such as livestock keeping, can be added [16]. It thus gives an opportunity for smallholder farmers to improve on their livelihood by making more cash (see figure 2).

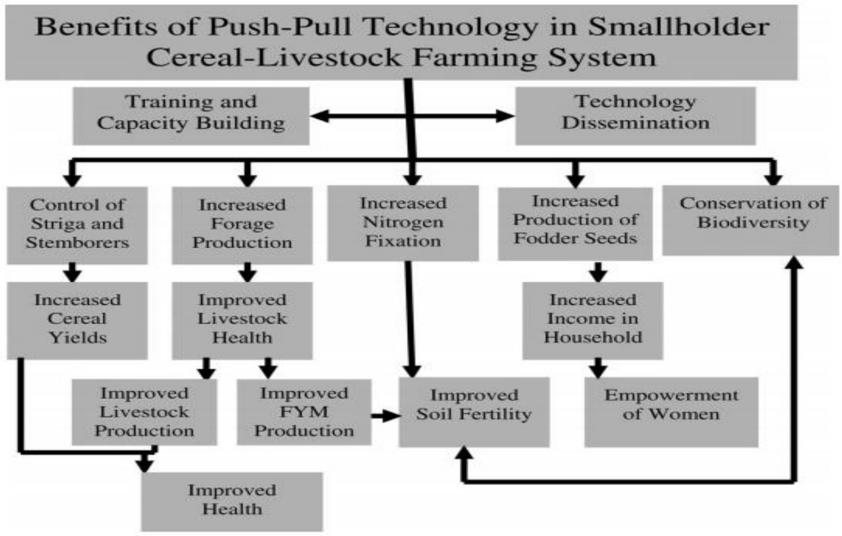

Figure 3: Benefits of push–pull technology in smallholder farming systems. Source: [16].

2.3. Agroecological Innovations:

Agroecological practices are agricultural practices which aim at producing substantial amounts of food, by making high use of ecological processes and ecosystem services (nutrient cycling, biological N fixation, natural regulation of pests, soil and water conservation, biodiversity conservation, and carbon sequestration) via the best method, using them as vital elements in the development of sustainable innovations, and contribute to improving the sustainability of the agroecosystems [12]. Some of the agroecological practices have already been applied in varying degrees in different parts of Africa for years or decades, while others were recently developed and have not been applied widely [12]. This review looks at the soil nutrient management, tillage and residue management, agronomic practices, agroforestry, and soil and water conservation agroecological innovations in Africa and classify them according to author in [31] analytical framework.

2.3.1. Soil nutrient management

The rising decline in soil fertility of smallholder farms in Africa resulting from crop harvest removal, leaching, and soil erosion has led to the declining per capita food production. The imbalance of nutrient inputs and harvest removals and other losses, have given rise to the gradual decline in soil nutrient capital and it is reaching critical levels among smallholder famers [19]. Consequently, any sustainable soil fertility replenishment innovations should be focus on integrated nutrient management including the application of leguminous mulches, agroforestry, composting as well as technologies that reduce the risks of acidification and salinization [19]. Soil nutrient management techniques in Africa include; mulching, improved fallow, manure management, composting, and improve fertilizer use efficiency.

Figure 4: Mulching around banana crops (S. Shames/EcoAgriculture Partners). Source: [19].

2.3.2. Tillage and residue management

Tillage management is any form of conservation tillage where residue, mulch, or sod is left on the soil surface to reduce soil disturbance, and decrease greenhouse gas emissions [19]. Residue management is the thorough handling, treatment, and utilization of plant and crop residues. It also entails maintaining cover on about 60% of soil surface during planting. It combines mulching, composting, integrative livestock and manure management and ideally allows at least 30% of the soil covered with crop residues after harvest to protect water quality.

Figure 5: Conservation tillage (H. Liniger). Source: [19].

2.3.3. Agronomic Practices

Agronomic practices are those techniques used by farmers to improve soil quality through better and environmentally friendly fertilizer management, enhance water use efficiency, manage crop residue and improve the environment. These techniques are economical due to decrease cost inputs and also improve the quality of the environment via decrease water and fertilizer use. Agronomic practices comprise four main techniques: Cover crops and green manuring; Intercropping, Relay cropping, Alley cropping, Contour strip cropping; Crop rotation; and Improved crop variety.

Figure 6: Alley Cropping. Source : [32**]**

2.3.4. Agroforestry

Agroforestry as defined by [33], is ecologically based natural resource management system that through the integration of trees on farm and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits [19] integrated animals to agroforestry by redefining it as a collective name for land use systems and practices in which woody perennials are deliberately combined with crops and/or animals on the same land management unit. The combination can either be in a mixture or in a temporal sequence for ecological and economic interactions between the woody and non-woody components. Agroforestry is based on three attributes; maintain or increase production, meets the needs of the present generation without compromising the ability of future generations to meet their own needs, and culturally acceptable and environmentally friendly.

2.3.5. Soil and water management

Soil management on one hand is the prevention and reduction of the amount of soil lost through erosion [19] through increasing the amount of water seeping into the soil and reducing the speed and amount of water run-off. Water management on the other hand involves improving water use efficiency to minimizing water losses. Soil and water management techniques include: storing water in reservoirs, drip irrigation to allow it to sink into the soil and increase soil moisture levels, using a protective cover of vegetation on the soil surface to slow down the flow of running water and spread the water over a large area [34]. A combination of drip irrigation and cover crops is also possible by adding cover crop rows between crops to reduce evaporation from bare soil, decrease soil erosion, increase soil organic matter, and increase N concentration if legumes are used [35].

3. Analytical Framework

The Hill and MacRae analytical framework describes an agricultural transition towards sustainable agriculture by defining three consecutive stages: efficiency increase, substitution, and redesign. Efficiency is characterized by changes to reduce consumption and waste of costly and scares resources (e.g., water, pesticides, and fertilizers) and improve crop productivity [31]. Substitution practices refer to the substitution of resource-dependent and environmental destructive products and procedures e.g., replacing chemical pesticides by natural pesticides [19]. While, redesign implies changing of the whole cropping or even farming system as a means of recognizing and preventing the causes of the problems. Note that one SAI could correspond to one or more categories of such a framework (Table 1). The Hill and MacRae Analytical framework analysis policy and institutions (governments, research and educational organizations, agribusinesses etc.) by looking at the content of decisions and process of arriving at the decisions. The framework makes minor changes on existing programs, operation, and regulations at the level of efficiency to create more positive environment for sustainable agricultural innovations. Such changes can be initiated and implemented at lower levels without any change in regulations [31]. Implementation of Substitution activities takes longer because it is concern with activities at more levels within the organization, and requires explicit approval from senior staffs. The redesign approach includes all the natural, ecological, and psychosocial laws and structures that are taken into account in its design and management procedures. Redesign requires more time to implement and demands greater changes to human and material resources than do other stages. Since the late 1980s, sustainability of agricultural policies and programs have received far less attention than institutional and organizational management. At the efficiency stage of this framework, minor changes are made to existing programs, operations, and regulations [31] to create more positive environment for those interested in using sustainable agricultural innovations to achieve SDGs. These changes are initiated and implemented at lower levels without needing any fundamental changes to policies and procedures [31]. Substitution activities require replacement of one product, activity, or technique with another making it more difficult to implement than efficiency stage. It also involves more levels of organizational structure, requiring explicit approval from senior staffs making more time consuming [19]. The redesign approach recognizes natural, ecological and psychosocial laws taking them into account in all design and management procedures. It is proactive and can potentially develop permanent solutions to problems thereby enabling sustainable development [31]. Furthermore, we distinguish between practices that are technologically and agroecological innovative since all practices are related to crop management and the management of landscape elements. In the case of technological innovations, we have LandPKS and the Push-Pull technology. In the case of agroecological innovations, we have practices related to soil nutrient management, tillage and residue management, agronomic practices, agroforestry, and soil water management (table 1).

4. Agricultural Policies and Institutions in Africa

African countries have a common umbrella, the African Union from which policies (including agricultural policies) regarding development are born. The policy organs in order of hierarchy are the Summit (Head of States and Governments), the Executive Council (Currently the Foreign Ministers of Member States) and the Permanent Representative Council (currently Ambassadors of member states accredited to the AUC) [4]. AU recognizes Regional Economic Communities (RECS) as her arms to aid development in Africa. They are 8 regional economic communities recognized by the African Union, these are: Common Market for Eastern and Southern Africa (COMESA); Community of Sahel-Saharan States (CEN-SAD); East African Community (EAC); Economic Community of Central African States (ECCAS); Economic Community of West African States (ECOWAS); Inter-Governmental Authority on Development (IGAD); Southern African Development Community (SADC) and the Union of Maghreb States (AMU) [4]. These RECS help to develop agricultural policies specific to their regions. The Comprehensive Africa Agriculture Development Programme (CAADP) has been the substance for defining national priorities, as well as enabling African countries to regain control of the dialogue with technical and financial partners. African public has shown limited commitment to boost agriculture and has thus failed to match the targets that were set in the “the first Ten years Implementation Plan” of the Agenda 63 [4]. Just about 25% of countries in Africa spend up to 10% of their public expenditure to agriculture. Alongside, the rise of regional integration and sector-based policies has help to speed up the structuring of Farmer Organizations (FO) at the sub-regional level. Nevertheless, FOs remain fragile and cannot replace public services supporting agriculture. Even though their networks are increasingly being recognized as key partners and integrated into various engagement processes by the public authorities at the national, sub-regional and regional levels, the FOs moved a step further to form the Pan African Farmers’ Organization (PAFO) in 2010. Africa has fewer Economic institutions compared to other parts of the world, especially in the financial and insurance sectors to aid agricultural development in the continent. This therefore hampers farmers’ ability to take more risks and to increase investment.

Table 1: Technological and Agroecological Innovations Practices. Each practice is briefly described and assessed according to the conceptual framework (efficiency increase (E), substitution (S), redesign (R)).

Type of Innovation Practice	Principle	ESR	Advantages and Constrains
Technological			
LandPKS	Uses mobile application for data collection and analysis.	S, R	Advantages: Supports local land management and land use planning to optimize food security, and climate change adaptation. Constraints: Needs a smart phone and knowledge of usage.
Push-Pull	Uses Desmodium to repel (Push) pest, kill weeds and increase soil nitrogen, and napier grass planted at plot borders to attract (pull) pest.	E, S, R	Advantages: decrease of water or product contamination from synthetic pesticides, decrease in risk for human health., increase crop uptake efficiency, enhance soil bio-activity, improve nutrient availability, and provide fodder for animal feed. Constraints: variable efficiency to control pests, restricted availability, low scientific knowledge, national regulations and registrations, may increase GHG emissions from soil-based tillage nature.

Agroecological Innovations **Soil nutrient management**	The use of crop residues/organic matter by farmers to cover soil, shorter or no fallow periods, and if need be, addition of organic manure and chemical fertilizers.	E, S	Advantages: Reduce fertilizer input, reduce risk of erosion, increase soil moisture, enhance crop uptake, and reduces GHG emissions from soil. Constraints: low scientific knowledge, variable and inconsistent effects, and low commercialization rate.
Tillage/Residue Management	Minimal or no tilling and uses residue, mulch, or sod left on the soil surface to reduce soil disturbance.	E,S,R	Advantages: Increase soil carbon/productivity, stabilizes soil structure, increases soil moisture, prevents erosion, limitation of weed growth, reduction of herbicide use, and reduces GHG emissions. Constraints: difficulty to efficiently control weeds, yield reduction due to competition between crops and cover crops/living mulch, uses high amounts of herbicides to weed control.
Agronomic Practices (Intercropping, crop rotations, Improved varieties etc.)	Integration of different crops in rotations, or coexistence of two or more crops on the same field at the same time or under sowing of relay crops in already existing crop.	E,S,R	Advantages: increase in land productivity, reduction of inputs, improved soil structure and fertility and facilitation of N nutrition for under sown crops. Constraints: lack of technical equipment for harvesting, risk of inter-species competition, pest facilitation, increase of complexity of system management.
Agroforestry with timber, fruit or nut trees.	Alley or scattered intercropping with timber, crops of woody vegetation and fruit trees.	E,S,R	Advantages: increase in land productivity, decrease in nutrient leaching and soil erosion, diversity of production, wood (timber, firewood) or fruit trees and crops protection of crops from intense solar radiation and wind, and increase in species diversity. Constraints: loss of cropped area in case of wood production, adequate management of woody rows, risk of competition between crops and woody vegetation.
Soil and Water Management	It uses techniques such as; storing water in reservoirs to allow it to sink into the soil and increase soil moisture levels, a protective cover of vegetation on the soil surface to slow down the flow of running water and spread the water over a larger area, and irrigation, drainage, and terracing techniques.	E	Advantages: Increase of water use efficiency and reduction of water use. Less risk of salinization of soils. Reduction of evaporation with cover crops or mulch. Constraints: increase in investment, equipment, and management costs

Policies and Institutions			
Modification of Procedures to speed up decision making process.	Modify existing programs to better meet stated policy, research and business goals.	E	Advantages: Empowers agricultural stakeholders to undertake new innovations without fear of being penalized. Constraints: lack of political will, and financial ability of the farmers.
Introduction of new policies and accountability in existing organizational structures.	Introduce policies, research, or techniques for sustainable agricultural innovations into current institutional structures and activities.	S	Advantages: Empowers agricultural structures to undertake and disseminate new innovations without fear of being penalized. Constraints: lack of political will, and financial ability by the structures.
Design of organizational structures and decision-making bodies to be compatible with sustainable development goals and realities	Adoption of sustainable development goals as goals of food systems, design and implement programs, research, product and services to meet them.	R	Advantages: quality and sufficient food with minimal or no environmental damages to aid sustainable development. Constraints: Lack of political will.

5. Promising Sustainable Agricultural Innovations in Africa

5.1. Scales of application, system change

Sustainable agricultural practices that boost agricultural production with little environmental damages are applied at different degrees in different parts of Africa and at different extends within the prevailing regional or national farming systems. Few farmers in African countries practice sustainable agriculture and in contrast, a large number are still on conventional practices. The application of the different sustainable innovations as shown in this review paper suggests the need for adjusting the farming system, either at crop management level or at the farming system level in both technological and agroecological innovations. The level of change applied to a single agricultural practice is usually low because the farmer will have to adapt or change only part of the crop management (Table 2) which is similar to efficiency or substitution practices. In contrast, when the practices require modification of the cropping or farming system, the necessary level of system change is normally medium or high because not only a single practice, but a much larger part of the system has to be reorganized or redesigned [19].

Table 2: Sustainable Agricultural Innovations, scale of application, level of system change, and integration in today's agriculture in Africa adapted from author in 31.

Sustainable Agricultural Innovation	Scale of application	Level of system change	Integration in today's agriculture Africa	Potential for the 2063
LandPKS	Landscape, Practice	Low-High	Low	High
Push-Pull	System	High	Low	Medium
Soil nutrient management	Practice, System	Low-Medium	Medium	High
Tillage/Residue management	System, Practice	High	Low	Medium
Agronomic Practices	Practice, System	Medium-high	Low	Medium
Agroforestry	System	High	Low	Low
Soil and water conservation	Practice	High	Low	Low

Practice=only the specific practice has to be changed or adapted. System=the cropping or farming system has to be changed or adapted. Landscape=multi-stakeholder agreement is necessary to apply management

5.2. Integration in today's agriculture and promising SAIs

Generally, most of the SAIs presented in this paper are still at a low level of application in Africa's agriculture. Soil nutrient management is the only most spread practice. This seems to be due the fact that residue and organic manure are used as a means of disposal but also because they do not require a high level of system change [19]. The rest of the practices in our opinion, have a high potential to be more broadly implemented by 2063 except agroforestry and irrigation which have already benefit from good scientific knowledge as well as broad experience of farmers. In addition, international treaties, policies and regulations, and agro-environment schemes from financial institutions and international organizations will probably enhance the implementation of more environmentally friendly practices that are less polluting and less reliant on external inputs. These agricultural schemes and regulations could enhance an extended use of LandPKS, Push-Pull, Tillage management and agronomic innovations. Until now, most of these SAIs have a low integration in African agriculture, and medium potential for the 2063 African development plan to be more broadly implemented. In contrast, soil nutrient management including organic fertilizer application, and crop residue management have already medium integration levels in today's agriculture, and high potential for the future.

6. Goals and Orientations for Future African Agricultural

Africa is faced with the daunting challenge of feeding 1.5 billion people by 2030 and 2.5 billion by 2050. The objective for the coming decades is therefore to ensure food security for this rising and urbanizing population, create wealth and jobs, in rural areas in particular, while reducing inequalities and vulnerability and protecting environmental and human capital". Fostering investment in agriculture means attaching greater importance to the economic environment in order to reassure agricultural producers and other agents in the agri-food value chains. This could be achieved by focusing on five priority areas:

- Increasing production more sustainably, while absorbing a growing labor force: by promoting the controlled use of inputs and agro-environmental techniques to manage soil fertility levels;
- Increasing labor use, which prioritizes an agricultural development model based on modernizing family farms; reducing risks to agricultural production and revenue, which implies first providing agricultural producers and farmers with appropriate financial services and, second, ensuring better functioning markets; and securing access to land, training of future generations of farmers and adapting to climate change.
- Promoting diversification based on high quality processed products by offering more standardized products in terms of taste, shelf-life, and increasingly compliance with health and environmental standards.
- Promoting efficient and more equitable value chain development by encouraging intra-country approaches.
- Making farms and agricultural systems more resilient to a changing environment: by building operational links between agricultural policy and social protection policy.
- Developing regional markets and controlling international integration.

6.1. Actions

The public sector must demonstrate the political will to develop ambitious policies structured around three main intervention areas: (i) the production of public goods; (ii) the use of economic policy instruments; and (iii) regulations. To contribute more decisively to sustainable change in the African agricultural sector, policies must draw from the following fundamental principles and guidelines.

i. Give much more emphasis to farming as a business, as a profitable venture, and raise the profiles of the farming profession;
ii. Promote change and transformation in agriculture according to Africa’s vision 2063, starting from within the continent.
iii. Foster trans-sectoral dialogue and encourage partnerships to ensure appropriation of and alignment with the agricultural development strategy;
iv. Anchor economic change and transformation in a political economy approach;
v. Affirm Africa’s interests in international negotiations and influence standards and rules of the game by supporting the new international balance of power;
vi. Encourage subsidiarity and adapt it to the political maturity of constituencies at the various levels of its implementation;
vii. Promote the systematic preference for sustainable agricultural systems from a socio-economic perspective (use of labor) and also from an environmental perspective.

7. Conclusions

Most SAIs such as LANDPKS, push-pull technology, agronomic practices, agroforestry, tillage/residue management, and soil and water management at landscape scale have so far, a low integration in today's African agriculture. They have only high or medium potential to be more broadly implemented in the African development plan of 2063. In contrast, soil nutrient management including organic fertilizer application, have already medium integration levels in today's agriculture, and high potential for the future. The most important parameters for a limited or broader application are;

- Existence of the innovations for a significant period of time,
- Existence of widespread farming and good scientific knowledge about the innovation,
- Existence of practical on-farm experience, and
- System changes and redesign of cropping systems.

For broader application of these SAIs in the continent, there is need to investigate the impacts of agricultural policies and institutions on the innovations during the deployment stage. Also, quantification of SOC and GHG emission from the innovations should be simulated to 2063 to aid choice of innovation.

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