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Review

Soil and Water Conservation in Africa: State of Play and Potential Role in Tackling Soil Degradation and Building Soil Health in Agricultural Lands

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Abstract: Africa's lands are largely vulnerable and threatened by soil degradation and low water availability, especially in semi-arid and arid regions, limiting crop and livestock productivity and farmer livelihood options. Therefore, in African agricultural lands, adopting/improving measures that conserve soil and water resources is crucial. This review aims to provide an update on soil and water conservation (SWC) in terms of farmer practices and research actions and explore how SWC technologies and practices represent a pathway to build or re-establish soil health and enhance sustainable agriculture in Africa. It also aims to increase knowledge on best-fit SWC approaches. Soil conservation, which includes measures of controlling soil erosion and maintaining or improving soil fertility, is inseparable from water conservation. On agricultural lands, the two are typically co-addressed. Increasing plant biomass production through improved water, crop and soil management practices, and managing this biomass judiciously, have direct and indirect impacts on conserving soils and water resources, particularly in drylands. This study focuses on rainfed agricultural systems. We discuss the barriers and challenges to scaling up best-bet SWC technological and management options. Moreover, we show that options, such as Conservation Agriculture (CA), Agroforestry (AF), as well as integrated soil fertility management (ISFM) and field-scale rainwater harvesting (RWH), remain promising for the preservation and improvement of soil health in Africa's farmlands and improving the resilience of agrosystems to climate change and variability as well as droughts.

Keywords: soil and water conservation; soil health; soil degradation; conservation agriculture; agroforestry; soil fertility management; rainwater harvesting; plant biomass; sustainable agriculture; Africa

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1. Introduction

Soil degradation is defined as the diminution of the current or potential capacity of soil to perform ecosystem services and functions, notably the production of food, feed and fiber as a consequence of the decline in the physical, chemical and/or biological properties of soil [1]. An estimated 65% of the total global area of degraded cropland is in Africa [2], affecting crop productivity and causing food insecurity. Climatic factors, particularly rainfall variability, soil erosion and poor farming practices, including continuous cropping with little to no inputs (nutrient mining), low organic matter (OM) due to residue removal, overgrazing along with biomass burning, excessive tillage and cultivating marginal land, have been identified as major causes for the degradation of agricultural lands [1,3–9]. Sustainable land management (SLM), which aims to sustain environmental integrity while managing land to meet food, fuel and fiber needs, constitutes a pillar to closing the gap between potential and actual crop yields [10] and includes soil conservation actions [11]. Although SLM is the first pillar of the Comprehensive Africa Agriculture Development Program (CAADP)'s four pillars of agricultural development in Africa, the adoption of improved land management practices remains low on the African continent [12]. Low water availability for biomass production is another major constraint in African rainfed agricultural systems, especially in arid and semi-arid regions (ASARs) characterized by low and erratically distributed rainfall [13]. A major characteristic of agriculture in Africa is that it is predominantly rainfed. Soil water availability, which determines the length and variability of the growing season [14], is influenced by climatic factors but also depends on soil properties and the implementation of sustainable soil management measures. Soil moisture (SM) has a marked annual cycle that is mostly influenced by how precipitation and evapotranspiration behave [15]. A basic principle of green water (i.e., the fraction of rainfall stored by the soil and available for plant uptake) management is to ensure the availability of sufficient SM to support crop growth. Under different soil management practices, seasonal climatic variations are a major parameter that can significantly affect SM, e.g., [16]. In ASARs, soil water availability may be limited by several processes, including high runoff, high evaporation, poor infiltration and low soil organic matter (SOM), which can cause low water retention, especially on sandy and sloppy soils, reducing the production of plant biomass. The low levels of biomass production will probably be exacerbated under future climates that are expected to result in even lower and variable precipitation and higher air temperatures in ASARs, negatively impacting plant water availability and agricultural production [17]. To mitigate all these challenges and increase biomass production, the adoption of practices that support soil and water resource conservation is urgently needed.

Soil conservation aims to control soil loss through erosion and the maintenance and improvement of soil fertility [18,19]. As for water conservation, it aims to increase the amount of water stored in the soil profile [20] by limiting surface runoff and increasing infiltration, reducing deep percolation and evaporation from the soil surface [21] and suppressing undesirable transpiration (e.g., through weed control) [22,23]. Coupling soil conservation and water conservation resulted in the combined concept of soil and water conservation (SWC) [24]. The SWC concept makes sense as the separate concepts of soil and water conservation often mobilize the same techniques [25]. The two concepts are also synergistic as soil conservation can facilitate water conservation through improved water infiltration, storage and maintaining adequate soil moisture content for crops. On the other hand, water conservation can control or reduce the erosive effects of water on soil (splash and rill erosion). SWC is defined as the wise use of land resources (i.e., soil, water, plants), the implementation of erosion control and water conservation technologies, and the use of appropriate cropping patterns to improve soil productivity and prevent land degradation, ultimately improving the user communities' livelihoods [26]. SWC is linked to the production and management of plant biomass. The latter represents the primary source of SOM, a means of recycling plant nutrients and the natural protection of soil (soil cover) against various agents (falling or running water, heat, wind). Low biomass production reduces soil cover leaving the soil vulnerable to erosion. Furthermore, biomass production depends on environmental resources, such as water and soil nutrients. When soil is degraded, its capacity to produce biomass is reduced [27]. Increasing biomass production is one of the main ways to restore soil productivity [28]. However, this biomass must be managed wisely to obtain the maximum benefit.

SWC technologies (SWCTs) include agronomic (cover crops, strip-cropping, intercropping, crop rotation, conservation tillage, conservation agriculture, contour tillage etc.), vegetative (grass strips, hedgerows, windbreaks, agroforestry systems, orchard strips, etc.), structural (terraces, check dams, water harvesting structures) and land management (fallowing, application of fertilizers, composting, manuring, sub-soiling to break the hardpan and drainage, grazing management) measures [21,29–34]. Nevertheless, these four categories of SWC are rarely used separately due to their complementarity [21,29].

This review provides an overview of SWC practices (SWCPs) and soil management systems related to Africa's agricultural lands, with a focus on systems and practices under rainfed agriculture. It assumes that conservation measures preserve soils from degradation and improve and favor soil health, including water availability. Several techniques, whether indigenous (local origin), exogenous (introduced) or improved (by research or by land users), are used in Africa as conservation measures [35]. In this study, we attempted to answer the following questions: (1) What is the current scientific knowledge on the African experience in SWC? (2) What are the potentialities and limits of successful adoption of the best SWC options, i.e., CA and AF, in Africa? (3) What are the major research gaps and other challenges with regards to promoting CA and AF in Africa?

2. Literature Review Methodology

This manuscript was written using a narrative review as the objective was to provide a qualitative overview and update on SWC in Africa to open up research perspectives. The selection of the literature was conducted using Google scholar (https://scholar.google.com), Science Direct (https://www.sciencedirect.com), Springer Link (https://link.springer.com) and ResearchGate (https://www.researchgate.net) search engines accessed between 7 January 2021 and 12 September 2022. First, we conducted a global search on the theme of the manuscript using the title itself and different terminologies: "soil and water conservation in Africa", "soil and water conservation in Africa in agricultural lands", "farmers practices in soil and water conservation in Africa", "technologies used to conserve soil and water in farmlands in Africa". Relevant research articles were then consulted, with priority given to the most recent studies (from 2000). In a second step, we focused on the best SWC measures, i.e., CA and AF, by conducting additional research on their status, benefits, constraints and challenges for the research community and beyond.

3. Common Practices of Soil and Water Conservation in Africa at the Field Level

Due to different agroecological conditions (i.e., climate mainly, but also soil type and topography), SWCTs may vary from one region to another. The African continent has a diversity of agroecological zones (AEZs), shown in Figure 1.

Climate is a major element that can influence the SWCTs adopted in a region. For instance, cover crops and mulching can be unpopular in semi-arid areas due to low annual rainfall, which can limit plant growth and biomass production [36]. However, mulching contributes to reducing the high evaporation rate that characterizes most ASARs. Topographical conditions also influence SWCTs. Soil erosion is especially problematic in areas with moderate to steep sloping and low vegetative cover [36]. In sloppy areas, structural (terraces, stone bunds, soil bunds, etc.) and vegetative (herbaceous or woody plants used alone or to reinforce stone/soil bunds) SWC measures contribute to tackling water runoff and erosion when used properly. In midland and highland areas, farmers can be more likely to adopt terracing as a SWCP, as shown by Kato et al. [37] in a study in Ethiopia. For instance, bench terraces can be used on medium to steep slopes (12–47%) [38]. Hillsides often provide loose stone, which is often the material of choice for conservation [39]. In addition, in sloppy areas, contour farming (i.e., conducting farming activities such as plowing, furrowing and planting across a slope as opposed to up and down it) is a key agronomic measure that contributes to SWC by forming crop row ridges that act as barriers to surface runoff, increasing infiltration and reducing soil erosion down the slope [40,41]. Furthermore, the agroecological conditions of an area dictate the choice of crops/varieties and, more generally, plants to be used in SWC on farmlands [36]. *Vetiveria zizanioides*, a key species in terms of soil conservation and soil quality improvement, used in vegetative strips, is a grass plant adapted to a wide range of climates and soils [42], which gives it the advantage of being able to be used in different AEZs. Although SWCTs have long existed in Africa, farmers and field officers have not had easy access to information to enable the selection of those that are suited for given (agro)ecological and socioeconomic settings [38]. Details on the agroecological conditions favorable to various SWCPs in Africa can be found in Namirembe et al. [38]. Some SWCPs used in Africa are summarized in Table 1.

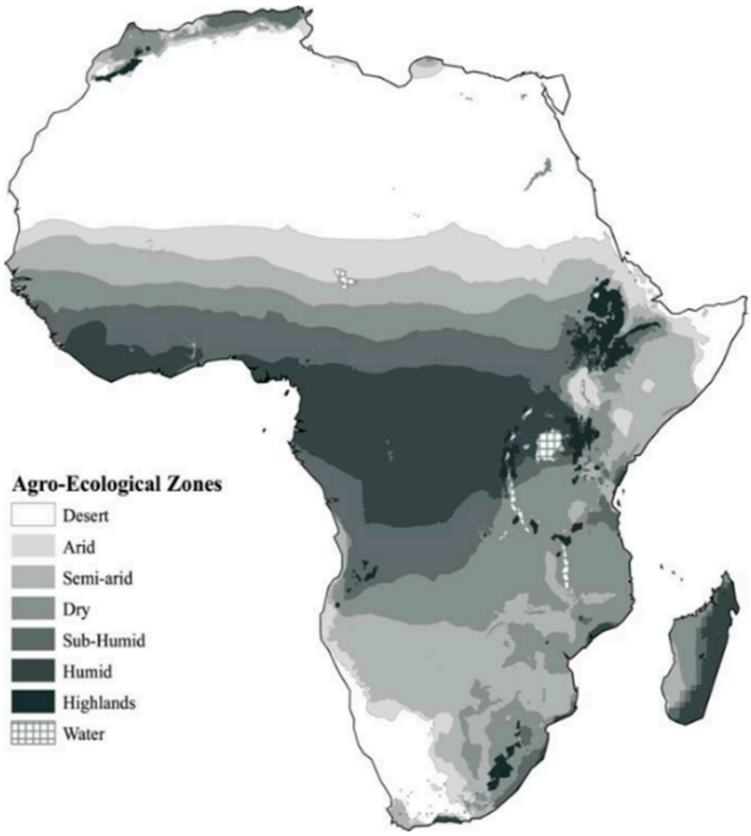

Figure 1. Major agroecological zones of Africa (Reprinted by permission from Springer Nature: Status and Trends in Land Degradation in Africa, Thiombiano, L., Tourino-Soto, I. 2007. In: Sivakumar, M.V.K., Ndiang'ui, N. (eds) Climate and Land Degradation. Environmental Science and Engineering. Springer: Berlin/Heidelberg, Copyright 2007 [2]).

Table 1. Some SWC techniques used in Africa.

Technique	Regions Where the Technique Is Used (e.g.)	Description of the Technique	Benefits	Limitations
Zai/Zay/Zaï/Za'i/Planting pits [1]	West, East and North Africa [35]	Digging small holes (depth from 5–15 cm and diameter from 10–30 cm with the spacing of holes between 50 and 100 cm) where crops will be planted with a hoe, using the rest of the soil to form a small dike downslope of the pits and enriching them with manure, compost or grass straw [43–45].	- Rainwater collection by creating a water pocket, organic input, recovery of degraded land, reduction in erosion [45]; - Restoration of degraded soils existing in the entire Sudano-Sahelian zone of Africa (rainfall from 300 to 800 mm) [46].	- Asphyxiation (by water) or burning (by organic manure) of plants in fairly wet or dry areas, respectively [45]; - Requirement of a significant amount of manure [47]; - Immobilization of soil N by soil microorganisms during straw decomposition when it is used [43]; - Labour intensive [46].
Stone bunds/lines/rows	West Africa [35], Eastern and Southern Africa [48]	Making strips of stones arranged on contour lines at a spacing from 15–30 m apart [45,47,49]. Stone lines can be used to form the framework of the system where there are a few stones available [41].	- Reduction in surface runoff [50] and erosion losses [45,47]; - Improvement of soil water storage, deposition of nutrient-rich sediments and yield gains [51]; - Regeneration of herbaceous and woody vegetation on degraded lands or pastoral lands [52]; - Stone strips can gradually form a horizontal terrace due to the deposition of soil transported by runoff or tillage [49].	- Availability of stones in the plots [53]; - Risk of an increase in the susceptibility of the soil to sealing and gullying due to significant removal of stones from cultivated lands (stones constitute protection of soil against raindrops and runoff) [2] [54].

Table 1. *Cont.*

Technique	Regions Where the Technique Is Used (e.g.)	Description of the Technique	Benefits	Limitations
Half-moons/ semi-circular hoops/ semi-circular bunds	West and East Africa [35], Morocco [55]	Digging of basins in the form of semi-circles open towards the top of the slope and surrounded downstream by earth levees in the form of half-moon extended by stone or earth wings [45]. Variations of this technique include triangular and trapezoidal bunds.	- Surface water collection, soil stabilization on steep slopes, recuperation of degraded soils [45]; - Harvesting of sediments (i.e., nutrients) in the basins and preservation of applied manure from loss through runoff [55]; - Effective technique in the regeneration of woody vegetation on agricultural and pastoral plots [56].	Difficulty mechanizing agricultural work, significant need for maintenance, loss of plot plantable area, economic profitability not apparent [45].
Contour ridging	West Africa [57]	Contour ridges (i.e., ridges are made parallel to contour lines) are small earthen banks (15–20 cm high), between which is a furrow that collects runoff from an uncultivated strip between the ridges [41,57]. The partitioned furrow technique, also known as tied-ridging, is a variation on ridging [41].	- Reducing runoff and erosion and improving infiltration and soil water storage [57]; - Efficient runoff yield because of the short catchment length [41]; - Increasing root growth and crop yield, e.g., [57]; - Practice easy to make (low labour requirements; hand tools can be used and) [41].	- Significant soil loss and rill erosion due to inappropriate design of contour ridge in sloppy areas [57]; - An increased hazard of gully erosion when contour ridging is used (alone) on steep slopes (over 25%) [54,58]; - Technique limited to areas with a relatively high rainfall (350–700 mm) [41]; - Heavy and compacted soils may be a constraint to construction by hand [41].
(Plant) mulching	Burkina Faso [24], Mali [45], Morocco [55], Senegal [21] and other regions	Soil covered with crop residues (mainly straw of cereals) or other man-made materials (plastic, for example, in vegetable crops).	Improving water, heat energy and nutrient status in soil, preventing soil and water loss, preventing soil salinity from flowing back to the surface, and controlling weeds [59].	- Need for high amounts of straw for good soil protection (up to 8 t/ha) [45]; - Residues may be entirely removed for use as biofuel or livestock feeding or grazed in situ by livestock, or burned off to "clear" the field [60].
Scarifying	The Sahel region [3] [45,61]	Scratching of the surface layer of the unploughed field with a tine device or hand work (hoe or daba) [45,61].	- Breakage of the crust formed on the soil surface, loosening of the soil, penetration of the first rains, gain in yield [45]; - Weed control [61]; - Low soil disturbance compared to ploughing (no soil turning and shallow soil depth affected) [61].	- Financial accessibility of the tiny device to farmers [45]; - Superficial and irregular results on dry soil, short duration of the positive effect on infiltration, operation to be repeated frequently, poor performance against weeds compared to ploughing, risk of erosion [61].
Terrace cultiva-tion/terracing (e.g., bench terraces, Fanya juu terraces, etc.)	East Africa [48], Cameroon, Rwanda, Sudan, Togo [39], Morocco [55], steep areas throughout Africa [21]	Dividing slopes into narrow but graduated steps facilitates the growth of different crops alone or in an agroforestry system [62]. Terracing can be carried out by excavating ditches, constructing earth and some stone bunds and vegetative barriers [63].	- Adapted to hilly or mountainous terrain [62]; - Reduction in soil erosion, conservation of water and nutrients [63].	- Requirement of considerable investments in terms of labour and operating costs [46,55,64]; - Risk of abandoning the structure as soon as their production is no longer profitable enough [55].
Hedgerows/ live fencing	Kenya, Cameroon, Rwanda [39]	Use of perennial species to delimit fields or protect them from livestock [55].	- Soil conservation by slowing down rainwater runoff and reducing erosion, as well as water conservation and biomass production by trees [50,65]; - Nitrogen (N) fixation (by legumes), upwelling of nutrients lost in deep drainage (by tree roots), and recycling by leaves (or faeces of grazing animals) [55].	- Competition with crops for light, water, and nutrients [55]; - Improved soil water profile may be accompanied by drainage that can cause leaching of elements, such as N, especially near the hedge or root asphyxiation [66].
Windbreaks	Usable in areas with high wind speed (more than 35 km/h) [38]	Planting of tree species, generally perpendicular to the wind direction [67].	Creation of a favorable microclimate, protection against wind erosion, loss of soil moisture and physical damage, and supply of firewood as well [67].	- Establishment is labor intensive and costly (purchase of plant material) [38]; - Need to control crop competition through crown and root pruning, loss of area and investment in labour [67].

Table 1. *Cont.*

Technique	Regions Where the Technique Is Used (e.g.)	Description of the Technique	Benefits	Limitations
Grass strips	Kenya, Tanzania [21], Burkina Faso [68], Ethiopia [69], etc.	Bands of grass are planted in agricultural fields across the slope and along contours at specified vertical intervals [39,70].	- Runoff and soil erosion reduction [68]; - An increase in water infiltration, improvement of soil water content and (possible) yield gain [71]; - Marking farm boundaries [39].	- Low density of the grass strip during the first years of establishment [68]; - Shading and competition effects on the growth of the crop located near the strips [68]; - Risk of harboring burrowing animals that can damage food crops [69]; - A combination with terracing is necessary to control erosion on fields with larger slopes [71].

[1] Variations on Zai include "Kitui Pitting"/"Kalumani Pilling" in Kenya [44], « Matengo » pit system (larger, deeper pits typically found on steeper slopes) in southwest Tanzania [39]. [2] A compromise acceptable to the farmers consists of keeping the small stones in place to protect the land and gathering the large stones in well-oriented stone strips to slow down runoff but also to reduce the slope length on land where it is problematic [54]. [3] The Sahel region corresponds to the semi-arid West Africa [21].

Other SWCPs used in Africa include:

- Meskat and Jessour systems in North Africa [35], which are traditional water harvesting techniques that make it possible to compensate for low rainfall and to cultivate various fruit trees and annual crops [55,72,73];
- Soil bunds, built by digging ditches and mounding excavated soils (embanked on the downslope of the ditch) [48]; a technique used in Eastern and Southern Africa for example [35,48];
- Trash lines, which range from simple bands of cereal and legume stover, as used in Uganda and Kenya, to the more sophisticated pegged brush lines of Sierra Leone [39]. Trashlines are semi-permeable barriers (as stone bunds) that allow the passage of excess runoff and trapping of sediments, and can serve as an effective and affordable framework for the construction of terrace banks [39];
- Grassed waterway, retention ditches, riparian vegetative buffer strip, etc., [38].

Economic constraints may limit the practice of some SWCTs. Beyond the establishment and maintenance costs (labor, plant material, specific tools, etc.) mentioned in Table 1, some SWCPs may limit agricultural production. For instance, terraces, despite their major interest in sloping fields, may cause farmers to lose cultivated areas, thus, decreasing land productivity and farmers' motivation to maintain these structures [38,74].

In Africa, especially in drylands (dry sub-humid, semi-arid, arid and hyper-arid lands), Agroforestry, Conservation Agriculture (including cover crops, rotations, intercropping), rainwater harvesting and integrated soil fertility management, are considered some of the most promising land and water management systems [21,75–77]. In what follows, we will take a closer look at these SLM options. We will especially focus on the potential of Conservation Agriculture practices and Agroforestry to support sustainable soil and water use on agricultural lands and, consequently, increase the resilience of agricultural systems to climate change and variability in Africa.

4. Conservation Agriculture in Africa

Conservation Agriculture (CA) is a farming system based on three principles: continuous minimum mechanical soil disturbance (i.e., no-tillage or minimum tillage), permanent soil organic cover with crop residues and/or cover crops, and finally, species diversification through varied crop sequences and associations [78]. CA is a suggested improvement on conservation tillage (any tillage and planting system that retains at least 30% of the previous crop's residue on the soil surface until after planting of the subsequent crop [79]), developed in response to the severe wind erosion caused by moldboard tillage and known as the American Dust Bowl in the 1930s [80]. Reducing soil degradation, improving the sustainability of agriculture and mitigating climate change through atmospheric C sequestration are key benefits associated with CA [81]. Soil water conservation is another major benefit of CA [82], especially in ASARs; CA contributes to increasing water productivity [83].

4.1. State of the Art of CA in Africa

In Africa, farmers use a variety of CA practices ranging from hand planting with pointed sticks and digging small permanent planting basins with specialized hoes and rippers to animal- or tractor-drawn seeders [84]. Examples of indigenous CA techniques in Africa include Zai pits, half-moons, Tassa water harvesting, agroforestry parklands, which have demonstrated historical success [84]. However, the practice of CA remains low in Africa, which has only 1,012,840 ha of the area under CA, or 1% of the world total [85]. Resource-constrained farmers in developing countries on the continent of Africa have rarely adopted no-till (NT) cropping systems with mulch, unlike large-scale mechanized farmers, particularly in the Americas and Australia [86]. Several socioeconomic factors may limit the sustainable adoption of NT systems among small-scale farmers in developing countries. These barriers to adoption include the possible lack of immediate comparative benefit of these systems, the additional labor required in the early years, the knowledge and skill requirements for maximizing the benefits that are usually lacking among smallholder farmers, the risk of low crop yields, the availability and cost of inputs (e.g., seeds of cover crops or herbicides, fertilizers, machinery) and the general focus of smallholders on their short-term objectives (e.g., meeting immediate household food security challenges) [86]. The adoption of CA in many countries of Africa is still relatively recent compared to some regions such as South America, the USA, Australia and Europe [87], although NT and mulching were tested in the 1970s in West Africa [85]. The practice of CA is still insignificant in most countries of Sub-Saharan Africa (SSA), in particular, with only small groups of adopters in Ghana, South Africa and Zambia [88,89]. According to Kassam et al. [90], farmers in at least 22 African countries promote CA: Kenya, Uganda, Tanzania, Rwanda, Sudan, Ethiopia, Swaziland, Lesotho, Malawi, Madagascar, Mozambique, South Africa, Namibia, Zambia, Zimbabwe, Ghana, Burkina Faso, Senegal, Cameroon, Morocco, Tunisia and Algeria. The successful adoption of CA on a large scale is relatively low among smallholder farmers [91]. However, in recent years, CA practice and adoption awareness has been increasing in Africa [85], particularly in Eastern and Southern Africa [87].

Even if CA is still not widely adopted in Africa, regional agricultural policies such as those of NEPAD (New Partnership for Africa's Development) or initiatives such as the "Triple-A Initiative (Adaptation of African Agriculture)" launched by Morocco at COP 22 in Marrakech would be likely to accelerate its diffusion throughout Africa [90]. Increasing awareness and adoption of CA in several African countries, such as Zambia, Tanzania and Kenya, have been achieved through, among other things, study tours to Brazil for farmers and policymakers, regional workshops, development and research projects in different parts of the world [85]. In some African countries, such as South Africa, Zambia, Zimbabwe, Malawi, Mozambique and Namibia, CA is "mainstreamed" into national agricultural development programs or supported by appropriate policies and institutional support [90]. In the ASARs of Morocco and Tunisia, which are characterized by low and erratic rainfall, where CA research and development has been conducted since the early 1980s, the adoption of CA is reported to be very promising [87,90].

4.2. Potential of CA to Tackle Soil Degradation, Build Healthy Soils and Conserve Water

Adopting new agricultural technologies such as CA by small-scale African farmers improves productivity and sustainability [92]. For Africa, CA would be a remedy for problems of soil degradation but also low agricultural productivity by reducing the risk of crop failure [89,93]. The role of CA in preserving lands, improving soil health and conserving water is well documented. One of the most important aspects of CA practice is the organic soil cover that impacts soil moisture balance, biological activity, accumulation of SOM and fertility restoration [94]. Water conservation is a key benefit of CA for African smallholder farmers given the erratic and unreliable rainfall in many parts of Africa [91]. Table 2 summarizes the positive effects of CA on soil health and water conservation.

Table 2. Benefits of CA on soil health and water conservation.

Benefits	References
Reducing runoff and soil erosion (i.e., soil and nutrient losses)	[80,82,83,85,87,89,91,95–97]
Moderating/buffering soil temperatures (in value and variability)	[80,87,98,99]
Preventing formation of crust at soil surfaces	[90,95,100]
Increasing SOM (especially in the surface layers) and minimizing its losses	[77,80,81,83,87,89,91,96,99]
Increasing soil moisture (less soil evaporation, reduced water runoff and increased water infiltration) and prolonging the availability of soil water to plants in times of drought	[80,87,89,99,101,102]
Favoring nutrient cycling and retention and biological nitrogen fixation (BNF)	[87,96]
Improving soil structure, soil aggregation and soil aggregate stability	[80,82,87,89,99]
Reducing soil compaction through soil biological tillage (by plant roots and soil fauna)	[80,99]
Increasing below and above-ground soil biodiversity	[80,82,87,90,99,103,104]

4.3. Addressing Constraints to the Successful Adoption of CA in Africa: The Role of Research and Beyond

CA properly implemented combines NT/minimum till, permanent soil cover by crop residue mulch or living plants (cover crops) and diversified crop rotations [94]. Successfully implementing all of these components is a real challenge, not to mention the need for inputs to maximize the benefits of CA, and for agricultural extension to promote the practice. When discussing the challenges related to the adoption of CA, we will focus on no-till (NT)/zero tillage/direct-seeding farming, including soil cover and crop rotations.

4.3.1. Implementing No-Till

NT is considered the key component of CA. In Africa, NT is typical in sandy soils and under shifting cultivation systems, where long fallows and slash-and-burn clearing improve the physical condition of the soil and ensure weed control (a major function of tillage) [105]. Although land preparation with a hoe is still common in Africa, in some areas it has evolved from the hoe towards oxen (or tractor) ploughing [39]. A long tradition of tillage among some farmers may be a source of reluctance to adopt NT [86]. In the interest of productivity and time saving, the mechanization of seeding operations on non-tilled soil is crucial. Even though NT helps save energy and labor and supports the conducting of early sowing (only one operation for sowing) [106], direct drilling may require more power than sowing in tilled fields [107]. The unavailability of specific NT seeders can be a barrier to the successful adoption of NT, e.g., [106]. NT seeders, either imported or locally manufactured, animal-drawn or tractor-drawn, have developed in different regions of the African continent, but especially for trial purposes [108–113]. More research is needed to adapt NT seeders to the conditions of small-scale farmers. The development of the NT machinery industry in Africa can be inspired by successful exogenous models, as was the case in East and Southern Africa, which benefited from the experience of Brazil [111,112]. The Moroccan experience in NT also deserves to be considered a model. In Morocco, local NT drill manufacturers and subsidies have promoted NT adoption. This is being enhanced by "Al Moutmir", an OCP phosphate industry initiative covering broad climatic zones in Morocco. More than 28,500 hectares have been converted to NT farming since the program was launched, with the help of agricultural associations and cooperatives nationwide and in collaboration with national research institutions [114].

4.3.2. Implementing Sufficient Soil Cover by Crop Residues

To maintain and improve soil quality and preserve land from degradation, CA requires a minimum of 30% soil cover [79] or approximately 3 t/ha of crop residues [115]. A major (biophysical) constraint to the large-scale adoption of CA is the availability of sufficient crop residues [95]. This constraint is linked to the existence of a relatively short growing season in ASARs, associated with low biomass production and competition for crop residues to be used as mulch due to their frequent use as fodder for livestock, as a household fuel or as construction material [88,94,113,116,117]. In addition, there is the constraint related to the inherently low soil fertility in African smallholder farms that can limit sufficient crop residue production and, thus, create a major obstacle to implementing CA [91]. Crop residues available in sufficient quantities for mulching purposes are often based on cereal straw (high C/N ratio), which can lead, especially in the early seasons, to problems with N immobilization due to low soil fertility [91]. In this situation, crop yield may decrease if fertilizers or crop rotations with legumes are not used to supply nitrogen [82,118].

Furthermore, in Africa, particularly in semi-arid regions, crop residues are often considered public goods [119], threatening their management. For instance, there is often uncontrolled post-harvest access to croplands for grazing by livestock in the local community. Regions with high biomass production and limited livestock pressure are considered well-suited to CA [120].

Overcoming challenges related to the low availability of crop residues requires management options, such as agroforestry, that produce additional biomass that can be used as fuelwood and fodder, reducing pressure on crop residues [95]. Limiting the burning of crop residues to clear agricultural lands, especially in the case of plots directly sown without tillage, is also a challenge [120]. In addition to consuming the residues, burning residues can harm soil life (mesofauna and macrofauna) and significantly reduce the soil's microbial activity when practiced continuously [121].

4.3.3. Scaling the Use of Cover Crops

Cover cropping is based on the use of "close-growing crops that provide soil protection, seeding protection, and soil improvement between periods of normal crop production or between trees in orchards and vines in vineyards" [122]. Cover crops (CCs) are an important companion to NT, reduced tillage, alley cropping, agroforestry and other conservation practices [123]. Regarding soil health, water conservation and crop productivity, CCs provide many benefits: protecting soil against erosion, preventing leaching of nutrients, improving soil physical properties, SOM and soil fertility, fixing N, recycling nutrients, improving water quality, suppressing weeds, increasing crop yields, etc. [123]. However, CCs are better suited to humid and sub-humid regions than semi-arid regions because they use soil water and can cause water shortage for the next crop when precipitation is inadequate [124]. When the CC and the main crop grow simultaneously on the same field, cover crop management, through the control of the CC cycle, is critical to reach relevant results, avoid water competition with the main crop and yield reduction. Instead of incorporating CC into the soil, the new trend is to use it as mulch, especially in areas with limited crop residue returns, where CCs offer additional cover [123]. In Africa, CCs such as *Lablab*, *Mucuna*, *Canavalia* or *Crotalaria* can be used as a mulch crop [84]. In compacted soils, several deep-rooted cover crops such as pigeon peas, *Canavalia*, *Mucuna* and *Lablab* can help break up the soil by penetrating the hard pans [84]. Many studies in Africa have demonstrated the benefits of CCs in improving the physical, chemical and biological properties of soils, e.g., [125–130], as well as boosting biomass production (fundamental to ensure minimum soil cover in CA), e.g., [131] in NT.

Scaling the adoption of CCs adapted to specific cropping systems and local conditions is another research challenge regarding the successful adoption of CA. Although CCs are not adopted significantly in Africa, their adoption is likely to increase if they have utility for feeding livestock, while providing benefits for soil health, mulching and weed control [84]. The use of CCs for fodder allows the integration of agriculture and livestock, the improvement in animal feed and the limitation of the traditional practice of burning natural ecosystems for extensive livestock, which remains the most widespread livestock farming method in Africa [132]. However, the integration of livestock into crop production needs to be considered wisely because it can potentially cause soil compaction, which reduces water infiltration and crop production, and threaten crop growth [133]. Given that communal grazing is a major problem for adopting CA in Africa, Derpsch [102] thinks that research should focus on finding unpalatable CCs to be used in communal grazing systems. He also advocates controlled grazing, fencing of field plots and stall-feeding. Furthermore, more research is needed about successful management of CCs. When starting a CC, N fertilizer inputs are required to maximize biomass yields, especially on soils where cultivation has resulted in a large loss of SOM (i.e., the main reserve of N in soils [134]) [126]. Phosphorus may also be required for legume CCs given the importance of this element in the BNF and the limited availability of P for many African soils [135].

4.3.4. Implementing Sustainable Crop Rotations

Moving from monocropping to crop diversification in NT systems is challenging, given that monocropping can be a barrier to fully adopting CA principles. Crop rotation, in particular, is fundamental to the sustainability of NT systems [136]. Since designing crop rotation is one of the few methods available for managing weeds and volunteers in NT systems, it is very crucial [137]. Crop rotations are also an essential component of CA regarding soil health and conservation. Beyond breaking the dominance of weeds and the life cycles of host-specific herbivores and pathogens, they allow [138]:

- The improvement in soil structure through the development of different rooting systems, resulting in less soil compaction and degradation and contributing to soil organic carbon (SOC);
- The diversity of crop residues, improving the quality of SOM (C/N ratio) and soil quality, mainly when leguminous plants are used (N Fixation);
- The reduction in soil erosion compared to intensive monocropping.

While crop rotations combined with tillage and plowing may have a negative impact on soil biodiversity, especially soil fungi, conservation tillage (i.e., NT and reduced tillage [139]) and rotations with legumes favor the diversity of soil microbial communities [140]. Crop rotations are known to be a key element in improving soil fertility in NT systems. It has been reported that compared to NT without crop rotation, NT with rotation favors yield increases, which are often used as an indicator for improved soil fertility [141]. However, crop rotations, particularly those incorporating legumes, despite their many agronomic and soil benefits, can be problematic as they may incorporate unprofitable crops for the farmer or require high labor inputs due to low mechanization. For instance, Thierfelder et al. [93], in a study of maize-based cropping systems in CA in Southern Africa found that rotations with pulses were less profitable than maize due to poor market conditions. They emphasized the need to consider the socioeconomic factors that limit the practice of rotations and crop associations before all CA principles can be applied. Economic benefits of rotations depend on the existence of functional markets for inputs (availability of seed) and outputs (marketing of grain) [93]. In ASARs, with the integration of animal production, crop rotations should target fodder production especially forage legume crops. This would alleviate cereal residues' intensive grazing and improve soil quality and animal feed.

In addition, rotations, through the integration of a fallow, can help conserve soil water in ASARs. Fallowing maximizes the storage of precipitation (in the soil) and increases water availability for the following rainfed crop under the low and erratic rainfall in ASARs [142]. In most North African countries (dominated by two-year wheat-fallow rotations), weeds and volunteer cereals are allowed to grow on the fallow (called weedy fallow) and provide valuable and cheap grazing for livestock [143]. However, weed control during fallow is mandatory to conserve soil moisture [22]. While shallow tillage has long been used to eliminate weeds in fallows (i.e., clean fallow), chemical control with herbicides has emerged as an alternative to tillage and allows for greater water storage [22]. In semi-arid Morocco, it was found that water storage efficiency is 1.5 times higher under chemical fallow (fallow with chemical weed control) than under clean fallow [144]. However, in this region, chemical fallow is not well adopted by farmers [145]. Bouzza [22] considers no-till management and no soil disturbance in the dry period after harvest a requirement for successful water storage by fallow in semi-arid regions. Besides being a good alternative to clean fallow, a well-performed chemical fallow could also contribute to reducing tillage cost [146]. Although clean fallow can lead to significant amounts of soil available nitrate-N at sowing of the following crop through OM mineralization, this nitrate-N can be exposed to leaching following intense rains that may occur under the Mediterranean climate [145]. Non-tilled fallows, by slowing down the oxidation of SOM and nitrification, can reduce the loss of N through leaching compared to ploughing practices [147]. While in the humid tropics the introduction of a legume as a cover crop in short fallows to improve soil N fertility and the yield of the following cereal crop has been found to be feasible, in drylands, where water is scarce, this is difficult to achieve [148]. In this sense, a challenge for research in drylands could be the identification of legume crop/varieties to be inserted in fallow periods and that can improve soil N fertility without depleting the entire soil water stock and affecting the following crop.

4.3.5. Access to Inputs to Maximize Benefits of NT

Access to inputs (herbicides, seed treatment pesticides, improved seeds, mineral fertilizers) and credit are also constraints to the successful practice of CA in Africa [89,120]. Gowing and Palmer [149] emphasize the need for African farmers to access fertilizers and herbicides to have substantial productivity gains, achieve food security and reduce poverty. For the specific constraint related to herbicides, their availability is essential as the issue of weed management is problematic in CA. Moreover, developing desiccating herbicides (paraquat in 1961, glyphosate ten years later) made NT farming viable [10]. Additionally, given the lack of organic resources to achieve the required soil cover, the appropriate use of mineral fertilizers in Sub-Saharan Africa (SSA) is considered a way to boost biomass productivity to reach or exceed the threshold of three tons/ha for other uses of crop residues [115]. It is considered the fourth pillar of CA in Africa by Vanlauwe et al. [115]. Increasing biomass production through the optimal use of fertilizers under CA also helps to meet the forage needs of livestock [118]. More studies are needed in Africa to investigate crop fertilization in CA taking into account the N immobilization/mineralization from crop residues and the N contribution of legumes. In addition, studying the effectiveness of herbicides and finding alternatives to the phenomenon of resistance for certain weeds are areas of research.

4.3.6. Agricultural Extension to Promote CA

Agricultural extension to promote CA and the training of farmers in CA techniques is another major challenge. The acquisition of new knowledge and know-how in CA implies long-term support by agricultural advisors, which is rarely possible due to the limited duration of development projects promoting CA [106]. Gowing and Palmer [149] highlight the knowledge constraint related to the empirical evidence of the benefits of CA, which remains derisory in SSA and the constraint on knowledge transfer. They consider the creation of innovation networks as a condition for the success of CA in SSA, as was the case in Brazil. All these considerations show that CA is a whole system requiring the involvement of different actors whose focal point is the farmer. The latter must learn and understand this practice to be successful. To strengthen farmers' understanding of the principles underlying CA and how these can be adapted to local situations, participatory learning approaches, such as those based on Farmer field school principles, are encouraged [87]. For a successful practice of CA, the collective organization is crucial among farmers to manage equipment, cultivation operations (sowing, herbicide application, etc.) and crop residues in the field [106].

Further details on the socioeconomic challenges to the widespread adoption of CA in Africa can be found in Mkomwa and Kassam [84].

5. Agroforestry in Africa

Agroforestry (AF) is another promising conservationist agricultural system that contributes to preventing, slowing or reversing land degradation while allowing continuing use of land to produce crops and livestock sustainably and also providing ecological and economic benefits [150,151]. AF is "a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as crops and/or animals, either in the same form of spatial arrangement or temporal sequence" [152]. In AF (a term that emerged in the late 1970s [153]), trees can be associated either with crop production (agrosilviculture), animal production (silvopastoralism) or with animal and crop production (agrosilvopastoralism) [154].

5.1. State of the Art of AF in Africa

Because of the many woody and non-woody products of plant origin (leaves, flowers, fruits, seeds, bark, saps, fibers, rhizomes, etc.) and the services they provide in different aspects of human well-being, woody species are essential for populations in Africa [155] and occupy an important place in cultivated fields. For a long time in Africa, most crops (yams, maize, pumpkins, beans, etc.) were grown under the cover of scattered trees, which are a crucial component of traditional land use systems [156]. For instance, farming systems of the Sahel region are characterized by the co-occurrence of woody plants with crops in the fields [157], while in the Sudano-Sahelian zone, the association of traditional crops with trees is almost ubiquitous [50]. In the Sahel sylvopastoral zones, fodder trees and shrubs contribute to the productivity of livestock (supply of fodder in the form of green leaves during the dry season, tasty flowers, fruits and seeds), especially during the lean period [158,159]. In addition, the woody-perennial species of this region provide various raw materials of great economic importance (e.g., of the very well-known gum Arabic, which consists of the secretions of several species of acacia [159]). Home gardens are a common AF practice (AFP) in many regions of Africa. They are typically located close to the house in fenced or hedged areas where garden crops are produced to supplement the staple food supplied by the field crops [160]. North Africa has several high-value tree-based agroforestry systems (AFSs), particularly associated with olive (*Olea europapea* L.) and palm trees in oasis and argan (*Argania spinosa*) cultivation, which have high socioeconomic and cultural value [161]. For instance, in Morocco, where AF is widespread in oasis and mountain areas [161], the *Argania spinosa* agrosilvopastoral system, applied successfully for centuries in traditional agrarian civilizations, is a multipurpose AFS providing fodder and oil while being a solution to land degradation [162]. The association of crops and trees is evident in Moroccan oases, as exemplified by the oasis systems of the Atlas Mountains, which are characterized by a rich diversity of crops, vegetables, fruit trees, fodder plants, livestock, etc. [163]. This mixed farming, along with crop rotation, makes a significant contribution to soil fertility and soil conservation [163].

5.2. Potential of AF to Combat Land Degradation, Favor Soil Health and Conserve Water

Since the emergence of AF as a scientific discipline, several research studies have been conducted to gain an in-depth understanding and generate evidence on its use as a soil conservation option [164]. As for CA, AF has several benefits in terms of improving the physical, chemical and biological properties of soils and water conservation, summarized in Table 3.

Table 3. Benefits of AF systems on soil health and water conservation.

Benefits	References
Controlling water erosion (soil protection by surface litter and canopy cover)	[101,164,165]
Reducing wind erosion (through the use of windbreaks), especially in dry areas	[98,101,164,165]
Improving soil fertility and nutrient cycling through decomposition of litter, prunings, crop residues, deep nutrient capture, reduced leaching and BNF	[46,151,164–170]
Improving SOM and soil carbon storage up to deeper soil layers	[151,165,166,169,171,172]
Reducing runoff and increasing infiltration	[101,173,174]
Restoring degraded land	[21,101,175]
Breaking up of compacted soil layers and creation of biopores by deep roots of trees, and improvement of water infiltration	[164,165,176]
Reducing water losses through non-productive evaporation	[77,177]
Redistributing moisture within the soil profile through the "Hydraulic Redistribution" mechanism	[178–182]
Improving soil microbial status and dynamics	[150,169,174]

5.3. Examples of AF Practices with Promising Potentialities for Soil Health in Africa

5.3.1. Agroforestry Parks (Parklands)

Agroforestry parks are widespread in SSA, as traditional AFSs where valuable trees, scattered over cropland and pasture, are protected and cared for [67]. They consist of growing crops in the presence of scattered trees at a density of between 20 and 50 trees per ha [165]. Parklands can also be associated with traditional livestock production systems through a slow process of species selection and management of tree density over long periods [165]. Common tree species of such systems in West and Central Africa, for example, include baobab (*Adansonia digitaria*), tamarind (*Tamarinda indica*), *Faidherbia albida*, shea nut or karité (*Vitellaria paradoxa*), néré (*Parkia biglobosa*) [67]. Beyond the human or animal consumption products they can offer, AF parks reduce water loss and nutrient leaching in the system, allowing better nutrient utilization [165]. They also play a role in improving soil C content through litter provided by trees and root decay. Bayala et al. [183] showed that SOC gradients around trees in parklands are due to the influence of trees, which positively contribute to soil carbon content (mainly through litter). This positive effect of tree presence depends on the rate at which trees cover the field since the tree's influence on soil C is limited to a certain distance depending on its crown [50]. Thus, maintaining trees in parklands is of great interest in semi-arid areas where soil carbon is a major factor controlling soil fertility [183] and in sandy soils with low cation exchange capacity (CEC) [50].

5.3.2. The "Assisted Natural Regeneration"

The development of AF parks can be made possible by enriching them with different species, whether planted or developed using the widespread technique of assisted natural regeneration (ANR) (commonly known as «RNA» in French-speaking Africa), [184] which consists of protecting and managing the natural regrowth (shoots) produced by tree and shrub stumps in the fields [185]. It is practiced in several countries, including Niger, Burkina Faso, Senegal, Kenya, Uganda and Ethiopia [186]. Compared to reforestation, ANR is relatively cheap and easily adopted by farmers with living tree stumps in their fields [157,185]. In addition to the wood and non-wood products produced by the ANR, this practice contributes to soil erosion mitigation, soil fertility and degraded land restoration through the presence of trees protecting the soil and providing mulch, the increase in the quantity and quality of manure (good woody forage availability) and the preservation of crop residues and cow dung (OM) from being used as fuel due to the availability of wood [185].

5.3.3. "Fertilizer Trees"

"Fertilizer trees" (N fixing tree/shrub legumes) are an AF practice promoted as a new (ecological) approach to soil fertility in Africa [187–189]. They are considered options for complementing and reducing the need for inorganic N fertilizer through biological N fixation (BNF) by legumes [190]. For instance, Akinnifesi et al. [191] report that for Eastern and Southern Africa, more than 60 kg N/ha/year is added to the soil by N fixing trees through BNF, and a 75% reduction in mineral N fertilizer requirements is possible through nutrient inputs from tree biomass. Furthermore, trees can contribute to P availability, either directly through P release during tissue decomposition and mineralization or indirectly by acting on P adsorption–desorption reactions [192] or P acquisition through Arbuscular Mycorrhizal Fungi (AMF). According to Akinnifesi et al. [191], "Fertilizer trees" can be used in different systems such as:

- Improved fallows or "sequential tree fallows" (deliberate planting of fast-growing species of woody legumes for 2–3 years to restore soil fertility rapidly [187,193,194]);
- Alley cropping (growing of food crops in alleys formed by hedgerows of trees or shrubs that are periodically pruned during the crop growing season to minimize the adverse effects of shading and competition with the food crops [195]);
- Biomass transfer (use of green manures from fertilizing trees in the form of green leaves and twigs that are moved from one place to another, generally in wetlands [191]);
- *Faidherbia albida* systems, which are commonly found in the semi-arid zones of Africa's drylands [19].

Faidherbia Albida, or *Acacia Albida,* is a crucial legume tree of interest for its hardy character and the loss of its foliage during the rainy season, which reduces competition for water and light during the crop growing season [191,196,197]. These species can increase soil OM and N under their canopy by between 50 and 100% compared to surrounding soils and water-holding capacity and yields of cultivated crops [164]. Beyond the yield gains of the crops associated with them or following their installation, "fertilizer trees" improve soil health and provide ecosystem services such as erosion reduction and C sequestration [191].

5.3.4. Alley Cropping with Fodder Shrubs in Drylands

In the ASARs, such as those of North Africa, alley cropping based on fodder shrubs has shown many advantages in cropland conservation beyond sustaining forage production. In these harsh areas (drought and salinity), fodder shrubs such as *Atriplex nummularia, Acacia cyanophylla* and *cactus* are considered suitable for cropland management and rangeland revegetation compared to herbaceous species, and their planting contributes to tackling feed shortage and erosion problems and other uses [8,198]. Oldman saltbush, for instance, is identified as a species with the potential to reduce soil erosion, restore SOM, boost crop yields and provide high incomes to farmers in alley cropping systems [198]. For instance, in Lybia, the combination of salt bushes (Atriplex spp.) with barley and range grazing has shown remarkable land rehabilitation and the maintenance of long-term productivity under average annual rainfall as low as 120–170 mm [162]. In ASARs of Morocco, where livestock (sheep farming) is a major component of farming systems, the strip-alley cropping system, which integrates *Atriplex nummularia* with annual forages (e.g., barley, barley/forage pea and oat/vetch mixtures, medics), is considered an option to improve feed production and quality while preserving soil, water and phytogenetic resources [199]. Chebli et al. [200], in a study conducted in Eastern Morocco, found that the association of *Atriplex nummularia*, which has a high content of crude protein and mineral contents, with barley, had positive effects on soil properties, and increased biomass and canopy cover of the atriplex by 15% and 10%, respectively, and allowed a 38.9% increase in barley grain yield. These species can also be adapted to drought, water and soil salinity [198]. Cactus is another example of key species of African drylands, which can be associated with annual crops, such as barley, through alley cropping, allowing continuous fodder production and the maintenance of soil quality [8]. Integrating fodder shrubs in croplands could also reduce pressure on rangelands (overgrazing) and crop residues (essential resource in SWC, CA especially) for animal feeding by increasing fodder supply. Thus, the integration of fodder shrubs and CA through alley cropping could be a pathway for sustainability and intensification of agricultural production in ASARs.

5.4. Addressing Constraints to the Successful Adoption of AF in Africa

5.4.1. Reducing Pressure on Trees and Shrubs

Woody perennial species are an essential component of AFSs. However, they can be affected by uncontrolled exploitation by humans as well as by climatic hazards. For instance, despite the multiple roles of sub-Saharan AF parks, they are undergoing severe degradation due to the combined effects of excessive tree cutting, grazing pressure and droughts [201]. In a study conducted in Benin, Barmo et al. [201] observed that the structure of the stands in the AF parks studied was characterized by the predominance of young individuals of woody species, both in terms of diameter and height classes, which revealed substantial exploitation of large-diameter individuals. In the "doum valley" in Niger, the doum palm (*Hyphaene thebaica*) stand, traditionally reserved as a pastoral area, was progressively degraded and shrunk under successive droughts and agricultural clearings due to growing demographic pressure [202].

In areas where the doum palm is associated with crops, Peltier et al. [202] have advocated the popularization of the ANR technique to enable farmers to reconstitute a sustainable AF park of adult palms. Fires are another threat: they are known to negatively influence biomass, especially litter, which they can consume completely [203]. The fate of tree prunings is another major issue. Prunings are often used as livestock fodder and a source of energy (fire) in many semi-arid and arid tropics, making them unavailable for improving soil fertility [204]. In addition, regularly removing prunings from alley crops may substantially reduce the yield of associated crops, as observed for maize in the arid and semi-arid tropics and the humid tropics [204].

5.4.2. Considering Agroecological and Socioeconomic Conditions in the Dissemination of AF

Different forms of AFS have emerged in various locations depending on the environmental, climatic, economic and sociocultural niches they occupy [151]. AF can be used in a variety of situations as long as the appropriate trees are chosen for the right ecological and socioeconomic conditions [38]. Several AF practices (AFPs) can be appropriate for various AEZs [151]. However, due to water requirements, multistorey AFS are more appropriate in subhumid to humid areas or under irrigated systems [21]. As for alley cropping and improved fallow, they are applicable in a variety of climates, from semi-arid to humid [21]. However, considering tree-crop competition for water, alley cropping is sustainable in areas providing at least 800 mm rainfall during the growing season [160]. In the subhumid and humid tropics, improved fallows are one of the most promising AF technologies, and they have recently demonstrated significant adoption potential in Southern and Eastern Africa [21]. Although they can be found in a variety of latitudes and AEZs, parklands are most common in the semi-arid and subhumid zones of West Africa, as well as in some areas of East Africa [21]. As for home gardens, while they thrive in the wet tropics, it takes a little more planning and effort to establish them in dry areas [160]. As mentioned above, AF has several functions (food production, fiber production, wood supply for energy, soil conservation, fodder production, etc.). The emphasis of an AF system or practice may change depending on agroecological conditions, even if various AFSs/AFPs can be applicable to any major AEZ [205]. For instance, soil conservation is the functional focus of AFSs in sloping zones (such as the tropical highlands of East Africa); woody species are mainly used as shelterbelts and windbreaks in windy areas; silvopastoral systems for the production of livestock (and fuelwood) would be a priority consideration in sparsely populated semi-arid savannas [205]. These different aspects must be taken into account. In addition, when transferring an AFS used in region X to region Y with similar agroecological conditions, socioeconomic and cultural differences in the different regions should be properly taken into account by technology transfer [165].

5.4.3. Wisely Choosing Trees/Shrubs to Be Integrated: Example of Improved Fallows

The adoption of improved fallow practices faces several constraints. For example, in eastern Tanzania, the main constraints identified by Matata et al. [194] were the lack of awareness of the technology among farmers and their inability to wait two years before obtaining direct benefits. In addition, studies in Zambia by Mafongoya et al. [187] showed that the practice of improved fallows using non-coppicing "fertilizer trees" (species characterized by the absence of regrowth when cut at the end of the fallow) might not prevent soil nutrient depletion over time, as opposed to fallows using so-called 'coppicing fertilizer trees', which ensure a continuous supply of OM to the soil from regrowth of coppice (cut and applied to the soil). In the Democratic Republic of Congo, Likoko et al. [206] report that multipurpose shrubs, such as *Cassia spectabilis* (or *Senna spectabilis*) and *Leucaena leucocephala* (two coppicing species [207]), contribute to fertilizing the same soil for several years with OM, N and other mineral elements as opposed to *Tephrosia vogelii* and *Sesbania sesban* (non-coppicing species [187]), which wither after the first cutting and require replanting every year as well as extra labor.

5.4.4. Other Challenges to Be Addressed by Research

Other constraints of a biological nature limit the success of the practice of AF. Indeed, AF can also be the source of competition between trees and crops. The latter compete for water, nutrients and light [158,176,208]. Due to water competition between trees and crops, AF can cause reduced crop yields (e.g., near the hedges in alley cropping [209]). For the water-related competition, using tree species with low water demand when water is scarce helps reduce competition between trees and crops while reducing tree densities, and using tree pruning allows for reducing transpiration and, thus, tree water demand [210].

The research community must address many other challenges related to the practice and dissemination of AF in Africa. Despite the substantial advancements in biophysical agroforestry research in Africa over the last decades, there are still science gaps to fill [167]. According to Mbow et al. [151], there are several knowledge gaps regarding which tree species work best under a given site; the synergistic interactions/compromises associated with different tree–crop–site combinations; the most effective extension methods for promoting AF; the best AFPs in terms of healthy and ecologically functional landscapes; the optimization of ecosystem services provided by AFSs; the behavior of AFSs in the face of climate change; the benefits of AFSs in terms of climate change adaptation compared to other land uses; and the potential benefits of AF to improve farmers' incomes through carbon payments. In addition, as mentioned before, AF must address the specific needs of local users (small farmers, pastoralists, households, etc.). Furthermore, the problem of reproducibility of the results obtained on station in the farmer's fields in terms of performance for some practices, such as alley cropping, has been reported by Fonton and Agbahungba [211]. According to the latter, for the specific example of the integration of woody legumes into crops, the poor results obtained under farming conditions made it possible to take into account the adaptation conditions of legumes, i.e., the initial P fertility of the soil necessary for BNF, the depth of the soil, etc. Furthermore, for perennial legume species (key component of AFSs) with low N-fixing capacity (e.g., *Parkia biglobosa*), more research is required to improve BNF, especially through inoculation with Rhizobium strains [158]. Fonton and Agbahungba [211] also invoke statistical and agronomic considerations lacking in the design and implementation of trials (e.g., overestimation of yield), the variability of climatic conditions, etc. There is also a gap in research on "barrier" AF systems (e.g., alley cropping along the contour of slopes through the use of strips of grass and other annual species to trap sediments and nutrients, slow runoff and increase infiltration), given that formal AF systems research, especially in Africa, was initially interested in maintaining soil fertility in annual cropping systems by using leguminous shrub species (alley cropping and tree improved fallows) [173]. Making AF land-use practices more productive and improving farmer incomes are now key research problems [167].

6. Rainwater Harvesting to Improve Land Productivity in Africa

Rainwater harvesting (RWH) techniques play a crucial role in SWC, whether on a watershed or crop field scale (Table 1). These practices contribute to improving infiltration (through runoff reduction), erosion control, soil nutrient enrichment (trapping of sediments), improving crop and pasture productivity, increasing biodiversity, groundwater recharge, suppressing soil salinity, etc. [212,213]. In situ RWH practices, which mainly refer to micro-catchments at the field level, enable overcoming dry spells by increasing soil water content [213]. The most commonly practiced and emerging in situ RWH techniques in SSA are ridging, mulching, systems of furrowing and pot-hoeing and conservation tillage [214]. Planting pits such as Zaï are considered the most simple form of RWH [41]. In the case of African drylands, RWH is seen as an opportunity to stabilize agricultural landscapes in semi-arid regions and make them more productive and resilient to climate change [213]. However, in SSA, where water and nutrient deficiencies are the main limiting factors for crop growth, maximizing the use of rainwater is only marginally beneficial as long as soil nutrient deficiency is not simultaneously corrected [68]. Improving nutrient management, stronger mechanization (for the construction of RWH structures), animal tracking and the combination of the best in situ RWH practices with traditional methods are major challenges regarding RWH in Africa [213].

7. Soil Nutrient Management in Africa: The Relevance of the Integrated Soil Fertility Management Approach

Soil nutrient management is crucial to all field scale SWC practices. It contributes to improving crop yields, especially on soils with low nutrient levels and inputs. Moreover, vegetative or structural SWC methods alone may not sustainably restore the fertility of an already degraded site: an additional nutrient input may be a necessity [46]. The aim of the Integrated Soil Fertility Management (ISFM) is to maximize the efficiency of nutrient and water use and increase agricultural productivity [77]. In recent years, the combination of fertilizers with OM sources (crop residues, leaf litter, manure, compost), which is the cornerstone of the ISFM, has gained interest in the scientific community on soil fertility [215]; the ISFM also includes the combined use of mineral fertilizers and other soil amendments, such as lime and phosphate rock [75]. Organic resources have long played an essential role in African agriculture and have been the basis of the second paradigm in soil fertility management in Africa in the 1980s [216]. However, organic inputs alone cannot guarantee sustainable (crop) production due to their quality and availability limitations [217]. For instance, manure and plant biomass are typically characterized by 1–4% N by dry weight (only a part can be mineralized) compared to 20–46% in mineral fertilizers in the case of N [218]. Compared to the sole use of mineral inputs, the advantage of providing the soil with organic inputs contributes to SOM increase. In addition, soil C is an energy source for soil biota, it is logical to advocate CNPK fertilization as an integral component of soil fertility management [10]. Vanlauwe and Giller [217] consider that using mineral fertilizers increases crop production and, consequently, the amount of OM returned to the soil by roots and possibly crop residues that may stimulate biological activity.

Several studies have reported that mineral fertilizer co-use with organic inputs is favorable for soil and crop yield. For instance, the synergic effects of the combined use of crop residues and fertilizers are proven in the Sahelian zone [219]. Bationo et al. [220], in a study in Niger, found that the use of crop residues (millet stover) in combination with chemical fertilizers (NPK) increased soil water use over the control in an average season, helped trap wind-blown soil and had higher soil OM, CEC, P, Ca and Mg saturation. More generally, crop residues produced in sufficient quantities contribute to optimizing the agronomic efficiency of fertilizers [221].

The integration of legumes into cropping systems is another crucial component of the ISFM [189,221–223]. The ability of legumes to fix atmospheric N has two main positive consequences: their role in improving soil N fertility and their value in improving the quality of fodder and mulch [224]. Legumes also help solubilize insoluble phosphorus (P) in soil, improve the soil's physical environment and increase soil microbial activity [225]. In cereal-based cropping systems, legumes can be used as cover crops, living mulch, fodder or food crops; this can be carried out through various methods, including alley farming, planted fallow and multiple cropping systems [226]. Doubled-up legume practice involves intercropping two legumes with complementary growth patterns and plant architecture in rotation with a cereal. It is another method of integrating legumes into farmlands; it improves soil fertility, as both legumes provide above and below biomass and fix N through BNF [101].

Two other examples of ISFM applications in Africa are dual-purpose grain legume–maize rotations in savannas and micro-dosing fertilizer in the Sahel [221]. In dual-purpose grain legume–maize rotations, P fertilizers are targeted at the legume phase to ensure good grain and biomass production, while N fertilizers are targeted at the cereal phase at rates below the recommended rates given the N contribution of the legume biomass. As for micro-dosing, it consists of applying a small amount of fertilizer inside the planting pocket or in close proximity [227]. This targeted fertilizer application improves its use efficiency, which is further enhanced when micro-dosing is paired with physical soil management techniques for water harvesting [221].

Overall, legumes are a key element in the management of soil N fertility. However, as already mentioned, BNF can be limited by soil phosphorus deficiency. BNF can also be affected by water stress under dry conditions [228]. Molybdenum, which is a key component of rhizobia N fixation, can be limited not only by low soil moisture due to its low mobility in the soil but also by acidic soil conditions [228].

Despite its many benefits, the adoption of ISFM remains low, and the current progress is slow in many smallholder farming areas [229]. In addition, sustainable soil fertility management in Africa cannot be achieved without a deep and broad knowledge of the level of soil fertility in the continent. Indeed, many agricultural areas are still unexplored despite numerous studies on soil fertility in Africa carried out by research institutes since the 1960s [230].

8. Conclusions and Perspectives

Soil degradation in Africa is a serious issue that needs to be managed through effective conservation measures. On the other hand, climatic variability, drought and inappropriate agricultural practices limit soil water status and crop water availability. Soil degradation and low water availability for plants are especially problematic in ASARs due to severe climatic conditions and low plant cover linked to low biomass production and, often, fragile soils. Our review shows that there is local knowledge in Africa regarding SWC. There is a prominent role for the research community to continuously improve existing practices and techniques and adapt them to farmers' different agroecological regions and socioeconomic realities.

SWC techniques have several benefits in improving soil productivity and crop yields, providing ecosystem services, preserving the environment and biodiversity, adapting to and mitigating climate change, improving farmers' livelihoods, etc. In terms of soil health, they contribute to protecting soil against erosion (i.e., loss of soil particles, SOM and nutrients), recycling/adding nutrients, maintaining/improving SOM, which feeds soil biota and enhances its physical and chemical properties, conserving soil water, which feeds crops and influences soil microbial activity and making the soil more resilient to harsh climatic conditions. CA, AF, ISFM and RWH are cornerstones of sustainable conservation management of soil and water resources in sustainable agriculture. CA and RWH practices appear to be the most promising options in terms of water conservation and mitigation of the effects of low and erratic rainfall and drought. As for the integration of trees in cropping through AF, it allows for an agricultural production less susceptible to periods of drought since the roots of trees go deeper than those of annual crops and sometimes reach the water table [158]. AF and CA, including legumes (grain and forage legumes, legume cover crops and trees/shrubs), can be low-cost technologies for building and sustaining soil health among resource-poor African farmers if there is consequent support from governments, NGOs, etc., in particular, in the acquisition of inputs and specific equipment, especially machinery in the case of CA. These technologies should be given special attention by national decision-makers in their sustainable land management policies and research and development priorities. The role of extension for technology transfer and research and development are crucial for mitigating soil degradation and enhancing water and soil conservation to improve crop and animal production and ensure food and nutrition security in Africa.

The following perspectives should be considered by research for the broad success of SWC techniques in Africa:

- A more extensive exploration of the complementarity and synergies between SWC and other practices to be integrated.

As mentioned above, SWC techniques are complementary, and research should be able to explore and maximize the synergies between them. For example, CA works well with trees and shrubs and can be combined with AF [87,231]. The practice of CA with fertilizer trees has been observed in Zambia, Malawi, Niger and Burkina Faso [231]. Additionally, the use of biochar, which is another soil productivity management approach, has the potential to be integrated with CA [232]. In several regions in Africa, the combination of erosion control/RWH measures (e.g., stone barriers, zai, half-moons, hedgerows) and soil fertility management (compost, manure, mineral fertilizers) has proven beneficial in terms of crop yield gains [68,233]. Ridge-Furrow Mulching System (RFMS, i.e., covering the topsoil by inserting plastic film, crop straw, gravel sands and rocks in the ridges and furrows, before or soon after sowing) is another SWC practice that enhances soil moisture, water availability to plants, water and nutrient use efficiency, optimizes soil temperature and mitigates wind and water erosion [234–236]. This approach is all the more relevant since high evaporation can intensively restrict the effectiveness of technologies such as reduced tillage and in situ RWH to improve the precipitation use efficiency and yields of some crops [237]. The potentialities of RMFS are well proven by studies in East Africa [237–240]. Water use efficiency in rainfed systems can also be increased by using crops and/or varieties that use water more efficiently or that can extract water from greater depths in the soil profile (i.e., deep-rooting crops/varieties) [98]. This also allows an adaptation to crop stress caused by extreme droughts and higher temperatures [98]. Other cropping practices, such as the bio-control of pests (e.g., push–pull technology) and diseases, contribute to agricultural sustainability and resilience to a changing climate [100,101].

- Implementing long-term trials to evaluate the effects of CA and AF on soil quality and crops.

Measuring the impact of agricultural practices on soil quality and crop productivity generally requires long-term experiments given no significant results could be obtained in the short-term [127]. For instance, on-farm experiments have demonstrated that CA and AF may not cause immediate improvement in the soil's properties or crop productivity [100]. CA may cause yield losses or no yield gains in the short term, which could last up to 15 years, especially if starting from degraded soils [91]. In addition, long-term trials allow to establish and confidently recommend best management practices [241]. Long-term data could also allow us to assess the impact of land use change, climate variability and climate change. However, long-term experiments to evaluate the effects of CA or AF seem to be scarce and insufficient in Africa.

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