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Review

Multifaceted Impacts of Sustainable Land Management in Drylands: A Review

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Abstract: Biophysical restoration or rehabilitation measures of land have demonstrated to be effective in many scientific projects and small-scale environmental experiments. However circumstances such as poverty, weak policies, or inefficient scientific knowledge transmission can hinder the effective upscaling of land restoration and the long term maintenance of proven sustainable use of soil and water. This may be especially worrisome in lands with harsh environmental conditions. This review covers recent efforts in landscape restoration and rehabilitation with a functional perspective aiming to simultaneously achieve ecosystem sustainability, economic efficiency, and social wellbeing. Water management and rehabilitation of ecosystem services in croplands, rangelands, forests, and coastlands are reviewed. The joint analysis of such diverse ecosystems provides a wide perspective to determine: (i) multifaceted impacts on biophysical and socio-economic factors; and (ii) elements influencing effective upscaling of sustainable land management practices. One conclusion can be highlighted:

voluntary adoption is based on different pillars, *i.e.* external material and economic support, and spread of success information at the local scale to demonstrate the multidimensional benefits of sustainable land management. For the successful upscaling of land management, more attention must be paid to the social system from the first involvement stage, up to the long term maintenance.

Keywords: drylands; restoration; rehabilitation; land management; participatory-approach; WOCAT

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1. Introduction

Land degradation and desertification are mainly caused by land mismanagement, such as intensive agricultural practices, inappropriate use of irrigation, overgrazing, deforestation or urban sprawl, and driven by underlying forces such as a weak implementation of policies, national and international market demand, and poverty [1]. Bai *et al.* [2] indicated that 24.53% of land was degraded, and more recently the Food and Agriculture Organization of the United Nations (FAO) [3] (pp. 112–113) stated that, globally, 25% of land is severely degraded. These figures indicate that we are not doing enough to protect our land. This lack of effort will have enormous impacts on food security [4], climate [5] and human and environmental health [6]. Often, the reason for inaction lies in a trade-off between immediate human needs and ensuring long-term continuation of ecosystem services [7]. The economic consequences are increasingly recognizable as ecosystem services are lost when land is kept degraded [8,9]. The report "The Value of Land" launched by the Economics of Land Degradation Initiative provides evidence on ecosystem services, value losses from land degradation, and estimates that the global loss of ecosystem service values may cost between USD 6.3 and 10.6 trillion [10]. Losses of ecosystem services include provisioning services such as food, fresh water, timber, fiber; regulating services such as pollution control; cultural services; and supporting services such as nutrient cycling, soil formation or water filtering. Its sustainable use will help to reduce poverty in all its dimensions [11,12]. The recently adopted UN Sustainable Development Goal, goal #15, explicitly stresses to "sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".

The United Nations Convention to Combat Desertification (UNCCD) is trying to encourage global cooperation to support sustainable land management (SLM), the restoration of degraded land and raise awareness of the global benefits of soil and land generation and preservation [13]. Actions to combat desertification and land degradation can be broadly classified as prevention, mitigation, and restoration interventions [14]. The SLM concept was developed at the 1992 Earth Summit and first used by Smyth and Dumanski [15] based on criteria of productivity, resilience, protection, economic viability, and social acceptability. Many SLM practices proven to be effective in mitigating threats to drylands [16] are characterized by flexibility and multifunctionality in approach [17] and require a watershed or landscape perspective so that off-site impacts are kept in mind [18]. Some key principles in the reduction and mitigation of land degradation have emerged from proven practices, namely maintaining and enhancing soil cover, reducing top soil disturbance and compaction, rotating and interplanting crops/plants, integrating crop and livestock systems, enhancing plant and animal species diversity, and balancing nutrient withdrawal and replenishment [19].

Various SLM practices have been considered in many scientific papers on land restoration and rehabilitation in recent decades, but unfortunately established scientific evidence rarely drives adoption of SLM practices, mainly due to the lack of connection between science and practice [8]. Policies, in general, have also not furthered the adoption of SLM practices because they have not recognized that landscapes are social–ecological systems [20]. As a result, policies may be contradictory, subsidies inefficient [21], or practitioners not conscious of environmental and socioeconomic benefits of sustainability and habitat restoration. In this puzzling context, policy makers must consider the combined social–cultural, economic and ecological benefits of SLM projects whilst accounting for trade-offs as well as off-site effects [16].

To upscale SLMs, there must be proper recognition of local traditional practices and experimentation [22], a favorable cost–benefit ratio [23,24], local policy and tenure arrangements [25], and a participative approach [22,26–28]. Social involvement must be ensured for the adoption process of SLM practices to be achieved. Various international, national, and local institutions or projects (e.g., FAO-LADA, EU-DESIRE, EU-PRACTICE or WOCAT) have supported the upscaling of SLM. In particular, the approach taken by the World Overview of Conservation Approaches and Technologies (WOCAT) is based on a network of SLM specialists as well as a continuously expanding database system to provide SLM experiences and guidelines for best practices [19,27,29,30].

The aim of this review is to highlight keys to success for upscaling SLM and to contribute to the efforts made by the UNCCD to achieve environmental sustainability. The review gathers technologies, approaches, and strategies of SLM in various natural and social contexts, showing their multidimensional impacts on ecosystem services. Scientific papers, as well as case studies from the global WOCAT database, were included as sources of documented successful land management practices. Additionally, this review benefits from the broad and long-term field experience of the numerous co-authors that have collaborated in a COST-Action on desertification focused on restoration of arid and dryland areas [31]. The current paper first presents results of a review of water management, and continues with case studies that focus on arable land, rangeland, forests, and sand dune restoration. Commonalities and lessons learned are summarized in the conclusion section.

2. Water Management

Climate change and inefficient use of water resources are having severe consequences both on water quality and availability, especially in dryland areas. Water management and water harvesting (WH) practices have shown promising results in reducing environmental risks, and improving crop yields while delivering positive impacts on other ecosystem services by increasing local biodiversity, improving soil conditions and promoting socio-economic benefits (Table 1). One of the techniques used to cope with increasing water scarcity is WH, defined as "the collection and management of rainwater or floodwater runoff to increase water availability for domestic and agricultural use as well as for ecosystem sustenance" [30]. The practice of WH is not new for people living in dryland areas of the world. In these regions, several types of indigenous WH systems have been practiced by local people for thousands of years [32]. However, most practices have been abandoned and in some cases forgotten [33,34]. Lately WH systems are receiving renewed attention.

Table 1. Some good practices of water management: impacts on biodiversity, water availability, soil quality, and socio-economic improvements. Key: ⍓: improvements, ⊕: increase, ⊖: decrease.

Water Harvesting (WH) (e.g., Country & References)	**Impacts on:**				
	Biodiversity	**Water Availability**	**Soil Quality**	**Economic Remit**	**Social Impacts**
Floodwater harvesting: *a form of water management where floodwater or runoff from intermittent streams are intercepted or diverted for agriculture and/or domestic uses.*					
Spate irrigation, Eritrea: [35–37]	⊕ crop diversification (cereals, vegetables)	⊕ water availability for plants/livestock ⊕ groundwater recharge	⊕ soil deposits: 13 mm/yr) on average ⊕ soil moisture ⊖ salinity <4 d S/m	⊕ crop yields by 50%–100% ⊕ farm income	⍓ food & nutrition security
Runoff and flood water farming, Ethiopia [38,39]	⊕ crop diversification (vegetables, fruits, grass)	⍓ water availability for crops and grass	⊕ soil moisture ⊕ water infiltration	⊕ crop yields ⊕ farm income	⍓ community institution
Jessour, Tunisia [34,40]	⍓ fruit trees growth and annual crops	⍓ water availability for olive trees	⊕ soil moisture	⊕ crop yields	⍓ food & nutrition security
WH from concentrated runoff, Spain [41,42]	⍓ resilience of systems	⍓ water availability for crops	-	⊕ crop yields ⊕ farm income	⍓ knowledge
Macro-catchment: *a method of harvesting runoff water from a natural catchment such as the slope of a mountain or hill.*					
Small earth dams, Zambia [43]	⊕ livestock population and fish farming	⊕ water availability for livestock, crops	-	⊕ crop and livestock yields	⍓ food and nutrition security

Table 1. *Cont.*

Water Harvesting (WH) (e.g., Country & References)	**Impacts on:**				
	Biodiversity	**Water Availability**	**Soil Quality**	**Economic Remit**	**Social Impacts**
Sand dams, Kenya: [43–45]	⍓ resilience of systems and bee keeping	⊕ water quantity/quality	⊕ soil moisture ⊖ evaporation	⊖ labor constraints	⍓ food & nutrition security
Sunken streambed structure, India [46]	⊕ crop diversification (vegetables, food legumes)	⊕ groundwater	⊕ soil moisture	⊕ crop yields	⍓ conservation food & nutrition security
Micro-catchment: *a method of collecting surface runoff or sheet (and sometimes rill flow) from small catchments of short length.*					
Planting pits and stone lines, Burkina Faso & Niger [47]	⊕ plant diversification (cereals, grasses, trees, fruits)	⊕ water availability for plants	⊕ soil moisture by 59%	⊕ sorghum yields by 33%–55%	⍓ conservation
Furrow-enhanced runoff harvesting, Syria [48]	⊕ crop diversification (olive, annual crops)	⊕ water availability for olive trees	⊕ soil moisture ⊖ soil loss and compaction	⊕ crop yields	⍓ community, national institution, knowledge
Fanya juu terraces, Kenya [19,49]	⊕ crops, trees, grass growth	⊕ water availability for plants-	⊕ soil moisture	⊕ crop yields⊕ farm income	⍓ community institution, knowledge
Roof top WH, South Africa [50]	⊕ vegetable gardening	⍓ drinking water supply	⊖ evaporation ⊖ greenhouse gases emission	⊖ risk of production failure	⍓ health status ⍓ conflict mitigation

2.1. Floodwater Harvesting Practices

Floodwater harvesting is a form of water management where small earthen or stone-built bunds intercept floodwater from intermittent streams to slow water flow to increase infiltration into the soil or to divert a portion of the floodwater to adjacent irrigable fields. Harvesting of floodwater makes use of water which otherwise would be lost to evaporation and uncontrolled runoff without any benefit. There are numerous examples of this type of water management in Africa, Asia, South America, and other dry land areas of the world.

The traditional spate irrigation system comprises several typologies: (1) a network of canals to convey diverted flood water that contains fertile sediments to the adjacent irrigable fields; (2) embankments to infiltrate water into the soil and deposit sediments on to the fields; and (3) field levelling to spread water uniformly over the field [30]. All of them require intense labor to construct and maintain, highly skilled technical knowledge, and local experience. In the arid areas of Eritrea, spate irrigated fields give 50%–100% higher sorghum yields than rain-fed sorghum [35,36] (Table 1). Apart from its demonstrated increase in soil fertility, yield, and food security, the spate irrigation system provides social benefits such as high levels of cooperation and organization at the community level [36]. In the semi-arid Ethiopia, high value crops, vegetables, and fruit trees are grown [37,38] (Table 1). However, the traditional spate irrigation structures are frequently damaged by heavy floods, therefore local regulations, organization, and collective actions by the community are prerequisites for successful management and sustainability of these types of WH practices [39] (Table 1).

The traditional *jessour* is widely practiced in the arid highlands of Southern Tunisia to irrigate olive orchards and annual crops [40] (Table 1). The runoff catchment area, the terrace, the cropping area, and dykes with spillways are impluviums that constitute *jessour*. These practices recharge aquifers and control flood and wind erosion. However, the long-term maintenance of these structures are threaten by high rates of migration to cities that reduce the available labor force [34].

In the drier areas of south-eastern Spain (300 mm annual rainfall), flood WH practices from concentrated runoff were widely used during Arab and Roman dominated eras but they have since been abandoned and forgotten due to social change, climate change, and/or technological developments [41,42,51]. In this region, small earthen- or stone-built bunds divert runoff or flood water towards cultivated fields that are planted with almond orchards or cereals [30].

2.2. Macro-Catchment Water Harvesting

Small earthen dams are intended to store the upstream water that can be used for irrigation later. In Zambia, the size of earthen dams vary between 50 to 100 m long by 4 to 8 m deep [43] (Table 1). Depending on the land tenure of the affected area, their establishment requires consultation and involvement of the local community, and usually technical and financial support from the government. In Africa in general, the construction of small earthen dams provides water for domestic use, increases crop yields, and helps to establish a water storage system for livestock.

Similarly, sand dams are simple, low cost and low maintenance structures that provide an improved, year-round local water supply for domestic and farming use. A sand dam is a stone masonry barrier placed across a seasonal sandy riverbed that traps rainwater and sand flowing down the catchment [44] (Table 1). Several hundred sand dams have been built in eastern Kenya in the past decade. Sand dams are applicable in drylands with seasonal rivers with sandy sediments and accessible bedrock [45].

Agrawal and Gandhi [46] (Table 1) discuss the sunken streambed structure called *doh* in semiarid India. Sunken streambed structures are excavations in streambeds that provide temporary storage of runoff water and to increase water yields from shallow wells for supplementary irrigation of annual crops by increasing groundwater recharge. This storage and later use of water facilitates the production of high value legumes that depend on irrigation. These structures are low cost, increase groundwater recharge, and give poor farmers access to water for irrigation. Maintenance is agreed through meetings of user groups. In Mohanpada, Madhya Pradesh, India 100% of land user families have implemented sunken streambeds with external economic and technical support. Spontaneous adoption is growing in neighboring villages.

2.3. Micro-Catchment Water Harvesting

Small pits (Burkina Faso and Niger) are holes of 20–30 cm diameter and 20–25 cm depth, spaced about 1 m apart, widely practiced in Burkina Faso (*zaï*) and Niger (*tassa*) in crusted or degraded croplands [47] (Table 1). They are intended to maximize rainfall and runoff capture and increase water infiltration for millet and sorghum crops. In some cases, *tassas* are combined with stone lines along slope contour to enhance water infiltration and reduce erosion. As it does not need heavy machinery this practice has been readily adopted by local communities [30].

In north west Syria, furrow–enhanced runoff harvesting to grow olive trees through annually constructed V-shaped earthen bunds (reinforced by stones) and enhanced by downslope ploughing is used extensively [48] (Table 1). This technology saves irrigation water during the dry season, enhances soil moisture storage, and stimulates olive tree growth. The down sides of the system are weed growth in the tree basin and additional labor. Improved runoff-harvesting efficiency can be achieved by applying organic amendments, stone mulching, use of drip irrigation and ripping land prior to planting [30].

Another example of microcatchment water harvesting comes from Lanzarote in the Canary Islands of Spain. In this island ten thousand funnel shaped hollow micro catchments called "zocos" are used to harvest water and grow grapevines on soils rich in volcanic lava derived nutrients [52]. A horseshoe shaped wall protect the grapes from the winds while volcanic granules absorbs moisture during the night to feed the plants. Today, this land management based on traditional local knowledge, is not only an effective SLM practice but is an interesting attraction for tourists.

Liniger *et al.* [19] provide several examples of terracing systems in steep areas of the dryland regions of the world, they are considered as WH systems, e.g., stone lines on low slopes in West Africa (Burkina Faso, Mali, Niger) and terraces locally called *fanya juu* in East Africa (Kenya, Tanzania, Uganda and also Ethiopia); these terraces are made by digging trenches and ditches along the slope contour. Soil is thrown uphill to be developed into bench terraces to prevent loss of soil and water and thereby to improve conditions for plant growth [53]. The weaknesses of these techniques are loss of cropping area in the terraced bund, high initial labor cost, risk of bund breakage leading to increased erosion, and competition between fodder grass and crop farmers [49].

2.4. Roof-Top/Courtyard Rainwater Harvesting

Roof-top and courtyard rainwater harvesting are WH systems designed to improve household access to water for drinking, sanitation, and home garden irrigation in dryland areas. The rainwater that falls on house roofs or compacted/paved surfaces in and around courtyards is captured and stored in closed storage facilities like tanks, jars, drums, or cisterns [50] (Table 1). The initial cost for construction is high and the storage systems have limited capacity. However, roof-top and courtyard rainwater harvesting could be tied with micro-finance activities and many water tanks could be built at once in order to reduce material costs. Some studies report that rainwater from rooftops generally meets the international guidelines of drinking water quality, while others show the reverse [54]. Water quality of a high standard is more likely to be achieved when the water storage facilities are covered, cleaned, and treated regularly with disinfectants such as chlorine. Moreover, awareness raising and training, particularly on sanitation methods, could enhance uptake and dissemination of the technology [30].

2.5. Constraints to Adoption and Upscaling WH Practices and Possible Strategies

The main constraint to implementation and adoption of the above-mentioned WH practices include lack of governmental policies (e.g., land tenure) in many dryland countries for motivating land users to invest in WH structures. This is due to insecure land tenure, as land is owned by the state [55]. There are also conflicts of interest and disputes on water rights regarding the distribution of water in the catchment, the storage area, and application area among the land users [34,56]. Although WH are low-cost technologies, they still require some initial investment for construction, operation, and maintenance of the structures. Moreover, socio-economic benefits gained by implementing WH techniques are often only fully realized in the long term [57], and community involvement and participation in the planning, design, monitoring, and evaluation in most WH projects is inadequate.

WH practices should not only focus on on-site effects but off-site effects as well. Downstream users often perceive that more WH activities upstream means less water, nutrients, and fertile soils for them, and these practices therefore pose a threat to their livelihoods. However, such perceptions should be dealt carefully through the integrated catchment management (ICM) approach, which ensure that upstream development is not at the expense of the downstream and *vice versa* [56]. It can be defined as coordinated planning and management of land, water and other environmental resources for their equitable, efficient, and sustainable use at the catchment scale [58]. Under this management, WH techniques are linked to the entire value chain from resource conservation to production-processing-marketing-consumption where the producers (*i.e.*, the farmers or herders) and the consumers (*i.e.*, the community at large) mutually benefit from the catchment. The WH structures installed in the upstream could have positive effects on downstream communities because of reduced flood hazards and soil erosion, reduce siltation in water reservoirs/dams, rehabilitation of degraded lands, and improvements to water quality. Once communities reap the benefits from the project, and feel a sense of ownership of the resources in the catchment, they will play an active role in upscaling the WH techniques for SLM.

3. Arable Lands

Due to soil degradation the amount of cultivated land per person has declined from 0.44 ha to less than 0.25 ha in recent decades, and is expected to continue decreasing in the near future [59] (p. 10). The trend towards scarcity of arable land is seen as a threat to the production of food and fiber. Effective efforts have been made to increase productivity on existing farmland through new machinery, fertilizers, and genetically modified crop varieties [60], creation of new arable land and rehabilitation of degraded land [60–62].

Sustainable land management (SLM) practices in lands that are farmed currently and the rehabilitation of degraded arable lands are key of land restoration as they have potential to achieve both high productivity and environmental sustainability at the local scale. The extrapolation of lessons learned from land restoration projects is complicated by the diversity of practices available to land users and the diversity of plot conditions including labor requirements, access to herbicides and nutrients, climatic conditions, and market constraints [63]. To be deemed beneficial yield increases and economic and social benefits of SLM practices in different contexts must be demonstrated.

Many overviews and assessments of SLM have focused on specific technologies like water harvesting techniques and yield improving strategies [50,64]; on bio-physical aspects such as water and soil quality [65]; on the impact of tillage on soil biotic community [66,67]. Other reviews have mainly evaluated economic productivity [68]. To further improve arable land sustainability knowledge obtained from these specific cases must converge to a more standardized, comprehensive, and global approach as suggested by the WOCAT program. The WOCAT framework distinguishes three types of SLM in arable land: (1) integrated soil fertility management; (2) conservation agriculture; and (3) structural and vegetative measures [19,27].

3.1. Soil Fertility Management

Integrated soil fertility management is mainly aimed at increasing yield [69], but spin-off effects have been noted such as the enhancement of soil structure [70,71], increases microbial biomass [72,73], and improves water infiltration [74,75] through additions of manures, compost, or mineral fertilizers. The use of green manure and low quantities of animal manure have been shown to increase and maintain soil fertility and biodiversity, while surface runoff and soil erosion are significantly reduced. A good example can be seen in Murcia (Spain), where an area of shallow to medium depth soils (20–60 cm) with limited precipitation (300 mm annual rainfall) is described ([76], Table 2). After several years of green manure use in these Murcian almond and olive tree plantations, less pest control is normally required due to increased natural pest control and ecosystem integrity. Importantly, the products grown under this ecological agriculture system command a higher market price than those grown under conventional production schemes, and hence land abandonment is disincentivised. The system strongly depends on agri-environmental subsidies. Only 5% of land users implemented the technology of green manure voluntarily. Barriers to adoption of SLMs are not biophysical, rather they center on the lack of willingness of farmers to change their traditional practices [77].

Soil fertility can also be managed by producing fodder crops. Tolay [78] in the dry area of Eskişehir (Turkey) describes the benefits of rotation plans for maize, alfalfa, sainfoin, vetch, oat, wheat, and barley grown for feeding livestock and as field crops. Dense surface cover of fodder crops protects the soil from wind and water erosion, increases soil fertility, improves plant and habitat diversity, and reduces soil salinity. Farmers in Eskişehir have experienced an increase in fodder quality, crop yield, and farm income after implementing soil fertility management. Ninety-five per cent of land users in the Keskin Watershed of Eskişehir have implemented this fodder crop production practice with financial support, and a slight growing trend towards spontaneous adoption has been perceived.

Table 2. Case studies on arable land management practices and their multidimensional impacts on biodiversity, water availability, soil, and socio-economic improvements. Key: SOM: soil organic matter; ⊕: increase; ⊖: decrease; ⍓: improvement.

Strategies and Case Studies (e.g., Country & References)	**Impacts on:**				
	Biodiversity	**Water Availability**	**Soil**	**Economic Remit**	**Social Impacts**
Integrated soil fertility management. *Practices aimed at improving soil organic matter and soil structure*					
Ecological production of almonds and olives using green manure, Spain [76]	⊕vegetation species and varieties	⊕infiltration	⊖runoff/erosion ⊕ground cover ⍓soil structure ⊕SOM/nutrient cycling	⊕farm income ⊕crop production/yield	⍓ food security ⊕ farm income
Fodder crop production, Turkey [78]	⊕plant, animal and habitat diversity		⊕biomass ⊕soil moisture ⊖runoff/erosion ⊖soil salinity	⊕fodder/+quality ⍓crop yield	95% adoption, stability
Seed priming and micro-fertilization, Mali [79]	⊖exposure of plants to droughts ⊕biodiversity	⍓excess water drainage ⊕rainwater- productivity	⊕soil fertility ⊕soil moisture ⊕soil cover/windbreak ⊕SOM ⊖water/wind erosion	⊕crop yields (50% increase) Diversification of production ⊖costs for purchasing fertilizers/⊖expenses on agricultural inputs (with manuring) ⊕farm income	⊖risk of crop failure Earlier harvest (yfood security) ⍓livelihood and well-being
Conservation agriculture. *A system characterized by three basic principles: minimum soil disturbance, a degree of permanent soil cover, and crop rotation.*					
No tillage preceded by subsoiling, Chile [80]	⊕plant, animal and habitat diversity	⊕infiltration	⊖runoff/erosion ~70% reduction ⊖ compaction ⊕ground cover	⊕farm income ⊕crop production/yield	⍓food security ⊖work load
Olive groves under no tillage operations, Crete [81]		⊕infiltration	⊖runoff/erosion ⍓soil structure ⊕SOM/nutrient cycling ⊕biomass ⊕soil moisture	= olive production ⊖ production costs ⊕farm income	
Reduced contour tillage of cereals in semi-arid environments, Spain [82]		⊕infiltration	⊖ 30% runoff ⊖ 50% erosion	⊖ 40% production costs	⊖downstream flooding, security
Reduced tillage of almonds and olives, Spain [76]	⊕plant, animal and habitat diversity	⊕infiltration ⊕water holding capacity	⊖runoff/erosion 60% reduction ⊕SOM ⍓soil structure	⊖50% work load & energy	
Morocco [83]	⍓ palatable species	⊕infiltration	⊕SOM ⍓soil structure	⊕farm income	

Table 2. *Cont.*

Strategies and Case Studies (e.g., Country & References)	Impacts on:				
	Biodiversity	**Water Availability**	**Soil**	**Economic Remit**	**Social Impacts**
Precision conservation agriculture, Zimbabwe [84]	⊕beneficial species ⊕biodiversity/biotic activity (long term)	⊕water quality/availability ⊕recharge of aquifers	⊕soil moisture ⊖evaporation ⊕SOM/soil fertility ⊕soil cover ⍓soil structure ⍓micro-climate ⊖runoff/erosion	⊕50%–200% crop yield ⊕farm income Time-saving production ⊕product diversification ⊖farm inputs (fuel, machinery cost, fertilizer)	⊖risk of production failure ⍓food (and water) security and human well-being
Conservation tillage for large-scale cereal production, Kenya [85]	⍓ resilience of systems	⊕infiltration ⊖ down-stream siltation	⊖0% to 20% runoff No soil erosion ⊕70%–100% ground cover	⊕economic growth ⊕ yield multiplied by 4 ⊖ 25% production costs ⊕ farm income ⊕fodder production	⊖damage to neighboring fields, security Diversification and rural employment creation
Structural and vegetative measures. *Structures or permanent vegetative strips that reduce slope steepness and/or length.*					
Progressive bench terrace, China [86]	⊕plant, animal and habitat diversity	⊕infiltration	Sediment retention ⊖soil erosion/runoff	⊕farm income	⍓food security ⊖downstream flooding and siltation
Woven Wood fences, Turkey [87]	Promotion of vegetation species and varieties	⊕groundwater level	⊕groundcover (>30%) ⍓soil structure ⊕SOM/nutrient cycling ⊕biomass	⊕crop production/yield (doubled, up to 1.3 Mg ha^{-1})	⊖downstream flooding and siltation
Vegetated earth-banked terraces, Spain [88]	⊕Biodiversity	⊕water supply through water harvesting	⊕soil moisture ⊖soil erosion/runoff	= or ⊕ production	⊖downstream flooding and siltation
Olive tree plantations with intercropping, Morocco [89] Aloe Vera living barriers, Cape Verde: [90] & Land reclamation by agave forestry, Mexico: [91] & Gully control by plantation of *Atriplex*, Morocco [92]	⊕plant, animal and habitat diversity ⊕plant, animal and habitat diversity	⊕infiltration	⊖soil erosion/runoff ⊖soil erosion/runoff	⊕farm income ⊕crop production/yield ⊕farm income	⍓erosion knowledge & conservation
Grassed *fanya juu* terraces, Kenya [93]	⍓Biodiversity	⊕infiltration ⍓water quality	⊖soil erosion/runoff ⊕soil moisture ydispersed runoff ⊕ground cover ⊕soil fertility	⊕crop yield ⊕fodder and grass production ⊕wood production	Community institution strengthening Attractive landscape ⊖risk and loss of production ⊖damage to off-site infrastructure
Konso bench terrace, Ethiopia: [94]		⊕water availability	⍓micro-climate	⊕farm income	⍓food and water security ⍓livelihood and well-being

Agricultural soils in many developing countries are nutrient scarce, and many smallholder farmers do not have access to affordable mineral fertilizers [95]. Micro-fertilization, consisting of applying small amounts of mineral fertilizer to the planting hole or pocket, could be a useful option for these areas. In Mali, a 50% yield increase was obtained for sorghum and pearl millet dry farming using the equivalent to just 3–8 kg fertilizer per hectare [79] (Table 2), instead of the usually recommended dosage being 10 or 20 times higher or more. Small quantities of fertilizer (0.3 g per seed) were applied simultaneously with seeds during sowing. In this semi-arid region of Mali (400–800 mm annual rainfall) with flat (0%–5% slope) low fertility soils, such a micro-dosing practice has a low value-cost ratio due to reduced costs for inputs and workload. Spontaneous adoption of micro-fertilization in Mali is high, reaching more than 50% of farmers in some regions. These practices should be combined with mulch, green manure, or organic amendments to ensure a soil fertility increase. The usefulness of micro fertilization and increased yield have been documented by other researchers in the Sahel [96]; in semi-arid West Africa [97] and Niger [98].

3.2. Conservation Agriculture

Conservation agriculture (CA) is characterized by minimum soil disturbance, crop rotation, and a degree of permanent soil cover. Conservation agriculture usually involves the use of herbicides which can be controversial [99,100]. In spite of this point of contention, the use of conservation agriculture is growing across the world [101,102]. The benefit of reduced fuel and labor costs have been major motivators for adopting CA, in addition, CA can accomplish a variety of agri-environmental objectives, such as erosion reduction, improving soil structure, and weed control.

According to updated figures published by FAO [103], the U.S. is leading the list of countries with more absolute area under CA with 23% of arable land under CA. In South America the adoption of CA has been especially quick, the MERCOSUR countries (Argentina, Brazil, Paraguay, and Uruguay) are amongst the top five countries in terms of surface area in the world using CA, and as a result about 60% of the total arable land in South America is under CA. In Brazil, the success of CA was linked to the creation of CA specific farm machinery since the 1980s [104]. Other South American countries such as Bolivia, Venezuela, and Chile have currently 10% of arable land under CA. For example, in south central Chile [80] (Table 2), producers demanded solutions to the severe problems of rural poverty and soil degradation they experienced. Public funding supported 50% of expenses for implementation (infrastructure, seeds or fertilizers). Additionally, farmers received training courses, visited demonstration areas, and attended public meetings and site visits. Because of the great results obtained by few farmers, the approach was adopted by others. Farmer to farmer communication was identified as a driving force for dissemination.

In Europe less than 3% of the arable land is under CA [103]. Countries in Europe with the higher percent of arable land dedicated to CA include Finland (9%), Spain (6%), UK (2%), and France (1%). CA is particularly beneficial in sloping areas (5%–15%) with shallow soils such as those frequently found in orchards and occasionally in cereal croplands in southern Spain [76] (Table 2). In the rural areas of southern Spain low income and low farmland productivity lead to land abandonment, erosion, and land degradation processes that cause both on-site and off-site damage. To combat this degradations orchard soils are managed by reduced tillage and seeding green manures. The use of green manures, in particular, is easily combined with organic agriculture. Adoption of CA is linked to availability of subsidies for the most part, although there is a moderate trend towards spontaneous adoption. Again in southern Spain, SLM of cereal crops [82] (Table 2) uses a rotational system of winter cereals under reduced tillage and fallow land. This combination benefits SOM and soil water infiltration in these cereal cropping systems of southern Spain after 2–3 years [105]. There is a noticeable lack of specialized training and awareness of land users in southern Spain [106]. Adoption of CA usually manifests itself with individualized adaptations per farmer. In spite of this wide typology of practices, according to the Ministry of Agriculture [107] the figures of adoption of CA in Spain have experienced a 50% increase in the last decade. Though farmers more likely to rely on their practical experiences and contacts with neighboring farmers [108]. Only the spontaneously growing cover crops has been used in Crete [81] (Table 2). *Oxalis pescaprae*, a drought resistant weed growing in winter and being able to protect the soil from the erosivity of rainfall, was used in this study case. Disc-ploughing was used in the Crete example once every four to five years to eliminate perennial vegetation and incorporate fertilizers and plant residues into the soil. Since production costs decrease without any reduction in olive oil production, farmers gain increased income and lessen off-site environmental impacts effects (*i.e.*, reduced downstream flooding and reduced groundwater/river pollution). After 30 years of CA in Crete, there is a moderate trend towards spontaneous adoption of the practice.

CA adoption in Africa remains relatively low. The time after initiation of CA needed to demonstrate yield increase, usually between two to five cropping seasons, may be too long to convince other farmers to adopt CA. Sometimes smallholder farmers are living at the edge of subsistence and they cannot afford such delay. Nevertheless, there are examples of CA implementation and trends towards spontaneous adoption. In central Kenya [85] (Table 2) where a large-scale commercial cereal farm is based on tractor-drawn equipment, CA has been adopted. In this case yield increased from 1 to 4 Mg ha^{-1} after 20 years of CA. Multiple socio-economic benefits have been realized, as well as ecological on-site and off-site benefits related to soil, water, and biological conservation. In Morocco, Al Karkouri [83] (Table 2) reports the change from a previous barley monoculture to a diversification of crop rotations including barley and other cereal species with legumes (oats and lupin) in Sehoul. Farmers increase fodder production, improve physical chemical soil conditions and reduce erosion. In Sehoul, Morocco, in spite of the initial voluntary adoption of 100% of local farmers, the use of this practice is declining due to the use of fertilizers which allow a crop/crop rotation and the fact that there is a high workload complicated by emigration of potential workforce members.

CA, like other SLM, needs to be targeted and adapted to specific biophysical conditions; particularly conditions related to climate, topography, soil drainage, and soil structure texture. For example, Precision-CA strategies are promoted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), FAO, and different Non Governmental Organisations (NGOs) in Africa's low agricultural potential zones. CA stipulates minimum tillage, soil protection by vegetation residues and rotation, and can also incorporate micro water-harvesting techniques and micro fertilization. Yield increases by 50% to 200% have been reported as well as improvements in soil and water quality in semi-arid areas of Zimbabwe [84] (Table 2).

3.3. Structural and Vegetative Measures

Structural and vegetative measures refer to structures or permanent vegetative strips that reduce slope steepness and/or length as integral for the restoration of cropland. Structural and vegetative practices have been widely used in the past in many different arid regions, particularly in orchards. For example, vegetated earth-banked terraces in almond orchards are described by De Vente [88] in Murcia (Spain, Table 2) to prevent erosion and downstream flooding, and it is noted that vegetated earth-banked terraces met with moderate voluntary acceptance. Similarly, in China, rolling and steep areas that are severely degraded and losing annually 60 to 100 tonnes of soil per hectare have been rehabilitated by building bench terraces with apple trees that virtually reduced erosion to zero [86]. This practice is well known by local farmers but labor costs have increased in recent years discouraging them promote the practice to their peers. Despite multiple environmental and socio economic benefits (Table 2), the research report a negative off-site effect on river flow. Stone embankments supported on the downslope side by trees and/or legumes are used in semi-arid areas of Ethiopia [94] (Table 2). Stone embankments are efficient at erosion control and favor soil fertility and water supply, particularly if water-harvesting techniques are simultaneously implemented. Barriers to prevent erosion can also be built by woven wooden fences [87] (Table 2) in moderately sloped areas of central Anatolia (Turkey), where soil and water conservation of fields lead to double annual yield of barley to up to 1.3 Mg ha^{-1}. They consist of wooden posts 1.5 m height inserted into the ground, and additional branches between the posts. Due to the high investment rates farmers expect state subsidies for further adoption of technology.

In order to prevent gully erosion and improve farmland income, land users in Sehoul (Morocco) have started to implement contour plantations of olive trees separated by intercropping strips of annual crops, with additional natural hedges of cactus to prevent livestock intrusion. Secondary benefits on soil and water conservation were noticed in the Moroccan experience. There is a strong growing trend towards spontaneous adoption of this practice in Sehoul [89] (Table 2). Many different species can be used as living barriers to prevent erosion and improve soil conditions e.g., *Atriplex halimus* in sloping areas of Sehoul, Morocco [92] (Table 2) or *Aloe vera* alone or combined with stone walls (on slopes higher than 30%) have proven to provide erosion control on steep slopes of Cape Verde Islands (Portugal), despite ecological benefits, its application is strongly linked to external economic support [92] (Table 2). In Mexico, the agave (*Agave inaequidens*) is planted in sloping and degraded areas. Amongst other benefits these plantations reduce overgrazing, stop erosion and the production of alcoholic mescal generates high income for the farmers [90] (Table 2).

The most effective approach to SLM in arable agriculture should consider the implementation of a variety of complementary SLM measures involving the whole community or watershed. Effective SLM approaches should simultaneously lead to improved production, combat poverty, improve soil fertility, and decrease erosion and fuelwood shortages. In Kenya [93] (Table 2) this multiple benefit was achieved through the building of *fanya juu* level bench terraces in combination with other vegetative systems, protection of springs, improvement of crops and animal husbandry, agroforestry, fish ponds, and fodder production. It is important to highlight that improvements in arable lands have to be in line with livestock requirements, particularly in poor environments as there are many competitions for alternate, higher value use of residues [109].

4. Rangelands

Rangelands are natural or near-natural ecosystems that comprise around 40% of the Earth's ice-free terrestrial surface [110,111]. Rangelands may consist of natural grasslands, savannahs, shrub lands, deserts, tundra, alpine communities, coastal marshes, and wet meadows [112], and can include lands revegetated naturally or artificially to provide a plant cover that is managed like native vegetation.

Over-exploitation during the last several centuries has led to significant rangeland degradation that is considered to be a threat to the ecological services these systems provide [113]. The degradation of rangeland systems has reached a critical level (e.g., [114]) as the systems have lost or are under a substantial risk of losing their previous level of social-ecological resilience [115,116]. Notwithstanding, substantial parts of the world's degraded rangelands are still heavily grazed and used in unsustainable manner [117–119].

Rangeland restoration techniques include passive strategies, such as grazing enclosures or rangeland resting [27,120]. Active approaches to rangeland restoration include managed and rotational grazing and improved well distribution for water access [19], control and reduction of shrub encroachment [121], vegetation reseeding (e.g., [122]), facilitating the succession of native species [123], and planting fodder shrubs and trees [124]. Nonetheless, the progress of rangeland restoration relies first and foremost on improved grazing management (e.g., [125]).

4.1. Passive Strategies

Pastoralism is facing increasing water and fodder availability problems due to expansion of cropland, overstocking and overgrazing, amongst other issues. A successful passive strategy to rehabilitate rangelands and support their sustainability has been promoted by the government of Niger by improving the distribution of points of available water, building water harvesting structures, and facilitating passageways for herds. An efficient network of water points is crucial to avoid overuse of vegetation around a limited number of wells. Soumaila [126] (Table 3) points out that the number of wells has increased from 7 to 58 in a decade. These wells were built by the local communities with support of different government and NGOs. Overgrazing problems have been reduced by 30%–40%. Some conflicts between agriculturalists and pastoralists can be prevented by the use of the so called "*couloirs de passage*" or passageways to facilitate livestock herd movements between pastures and water points. In Niger these "*couloirs*" are demarcated by stones or planting tree species [127] (Table 3). Peace between communities is the key result in the short and long term.

Grazing-free periods of 2 to 3 years are useful in cases of moderate soil degradation where vegetation still has a spontaneous restoration capacity. Use of grazing-free periods is a traditional practice that used to be respected by cattle holders but no longer is common. In the Béni Khédache-El Athmane area in Tunisia [128] (Table 3), this practice is subsidized (98%) and has been reported to increase fodder production as well as other ecological benefits particularly those related to soil organic matter, increase biodiversity, and reduction of erosion.

In some areas, temporarily grazing deciduous woodlands can be an alternative to grazing rangelands in order to prevent degradation of rangelands in the summer dry seasons. Borselli [129] (Table 3) reports that 50% of land users voluntarily adopted this practice. A controlled number of cows and goats are allowed to graze in deciduous oak forests of the Basilicata region (Italy) where the animals can still find green grass in the dry season. This prevents excessive stress on the surrounding rangelands and has positive environmental effects on soil protection, reducing flooding, and downstream siltation.

4.2. Improving Grazing Management

Improved grazing management may involve the combination of agronomic and vegetative measures such as the above mentioned passive measures, with plantation of grasses, shrubs, trees, as well as the application of compost to improve soil fertility. In the overgrazed highlands of Ethiopia, the local *desho* grass (*Pennisetum pedicellatum*) is planted by splits in combination with legumes and fodder tree seeds [130] (Table 3). These areas are permanently closed to livestock, therefore, fodder is cut and carried to feed cattle once a year. The government provides training, material and technical assistance, and monitors the establishment. After the initial peak in labor costs initially spontaneous adoption can be very high in this region of Ethiopia. Multiple benefits can be realized in terms of fodder and wood production, soil protection, increased fertility, and biodiversity enhancement. Lastly, socio-cultural benefits can also be seen including community institution strengthening, increased income, and improved household nutrition.

Another option for grazing management is to subdivide the grazing area into a number of smaller enclosures for sequential grazing in alternating enclosures. This has been called rotation grazing. An example of rotation grazing was described by Lindeque in South Africa [131] (Table 3) where the frequency of grazing, the number of animals per enclosure, and the domination of undesirable species are investigated. Since 1994, this practice is no longer subsidized, but farmers now realize the importance of grazing management in sustainable livestock production.

Table 3. Case studies on rangeland management practices and their multidimensional impacts on biodiversity, water availability, soil, and socio-economic improvements. Key: SOM: soil organic matter; ⊕: increase; ⊖: decrease; ⍓: improvement.

Strategies and Case Studies (e.g., Country & References)	**Impacts on:**				
	Biodiversity	**Water Availability**	**Soil**	**Economic Remit**	**Social Impacts**
Pastoralism and rangeland management. *Grazing on natural or semi-natural grassland, grassland with trees and/or open woodlands. Animal owners may have a permanent residence while livestock is moved to distant grazing areas, according to the availability of resources.*					
Rangeland resting, Tunisia [128]	Promotion of vegetation species and varieties	⊕infiltration	⊕ground cover +soil structure ⊕biomass ⊖soil erosion/runoff	⊕production (fodder, animal) ⍓income (20%)	Combat rural exodus
Couloirs de passage, Niger [127] Improved well distribution for sustainable pastoralism, Niger [126]	⍓Biodiversity	⍓water availability ⊕water quality	⊕live plant cover ⊖water/wind erosion Efficient and flexible way of managing sparse vegetation and low soil fertility ⍓micro-climate	⊕animal productivity ⍓production and survival of arid rangeland plants (fodder) ⍓diversity of livestock and goods that are produced ⍓crop yields	⊖production risks, ⊖vulnerability Peace between communities ⍓food security ⍓livelihood and well-being Diversification and rural employment creation
Controlled grazing in deciduous Woods as an alternative to grazing on rangeland, Italy [129]	Promotion of vegetation species and varieties	⊕infiltration	⊕ground cover ⍓soil structure ⊕biomass ⊖soil erosion/runoff	⊕production (fodder, animal)	
Grazing land improvement, Ethiopia [130]	⍓Biodiversity	⊕stream flow in dry season ⊕water availability/quality for livestock	⊕ground cover ⊕soil fertility ⊖soil erosion ⊕soil moisture	⊕livestock production ⊕fodder production/quality ⊕income (selling animals and their products)	⍓household diets (milk), improved health ⍓food security ⊕availability of livestock products on the market (lowers prices for consumers) ⊖downstream siltation and flooding ⍓ awareness
Rotational grazing, South Africa: [131]	⍓Biodiversity	⊕water availability/quality for livestock	⊕soil fertility ⊖soil erosion ⊕soil moisture	⊕wood production	
Integrated crop-livestock management. *In an integrated system, crop and livestock are produced within a coordinated framework including livestock management, fodder production and controlled grazing.*					
Grazing improvement by multiple strategies [132] & Grazing improvement by plantation *of Atriplex nummularia* in Central Morocco [133] &	Promotion of vegetation species and varieties	Stops rivers flooding Improve water retention capacity of andosols	⊕SOM Improvement soil surface functions	⊕fodder production/quality	
Farmers Heal the Land, Iceland [134]	⍓Biodiversity		⊖soil erosion ⊕ground cover Carbon storage Soil stabilization	Sustainable grazing recovery ⊕production (fodder, animal)	Deliver the land in better condition to the next generation Improve the image of the farmer sector

Improvement in rangeland and herd management has been reported in communal lands in Namaqualand in South Africa, a region having 50–250 mm annual rainfall. Livestock exclusion, brushpacking, dung mulching, microcatchments, planting functional species, and stones arranged in lines across the slope to form a wall to avoid rills and gullies are strategies used in Namaqualand to rehabilitate drylands [135]. The involvement of local communities has been stimulated by training and involving members of target communities as paraecologists (e.g., [132,136]), and including them as fulltime non-academic members into the research team. Local participants have valuable insight into the social fabric, local land management techniques, and strategies for rangeland improvement and can thus facilitate knowledge exchange and implementation of the restoration measures.

Quantifying the impacts of sustainable land management (SLM) practices on rangelands is challenging since contrasting results on the various ecosystem services may be found. There are complex social and economic implications that affect long term sustainability of the interventions to rangeland management, further complicating efforts to assess effectiveness of practices. In Morocco, extensive rangeland improvement interventions have been implemented in drylands, particularly in the Ouled Dlim area (central Morocco), which has become a well-known case study. In Ouled Dlim, several thousand hectares of *Atriplex nummularia Lindl.*, a fodder shrub native to Australia, have been planted since the mid-1990s [133]. Analysis of the impact of plantations of *A. nummularia Lindl.* on biomass production was positive and revealed that, on average, the plantation sites produced 2.21 to 3.61 Mg ha^{-1} of dry biomass more than the surrounding rangelands, with the best performing plantations yielding a difference of up to more than 7 Mg ha^{-1} [137]. The performance was however strongly dependent on the quality of management applied by the breeders. Field measurements also showed that plantations increased soil organic matter and overall soil surface functions [138]. However, the aridity-resistance of this halophyte plant, cause soluble salts to accumulate in the leaves (particularly sodium), and top soil alkalinity was also highly increased [139], thus threatening the soil health.

Iceland is an example of a European country where extensive sheep farming still relies on rangeland [140]. The growing season is short and natural succession or revegetation strategies may require long periods of time, just like in drylands. Up to 80% of its ecosystems can be categorized as rangelands [141]. Significant parts of these systems are severely degraded [142], mainly due to unsustainable land use throughout the centuries in combination with harsh climate, volcanic activity, and vulnerable soils [143–145].

In the latter part of the 20th century new agri-environmental policies were established in Iceland [123,140]. The most influential changes were related to: (1) a sheep quality control system where rangeland condition became a provision for sheep farming subsidy payments from the State [141]; and (2) a governmental cost-share rangeland restoration program on SLM called “Farmers Heal the Land” (FHL), established and run by the Soil Conservation Service of Iceland (SCSI) that has the official task of rangeland restoration since 1907 [134]. The FHL program is based on bottom-up approaches and close cooperation between farmers and the staff of the SCSI [140]. The program has been highly successful with regards to increasing trust between the related parties and its participatory structure and stakeholder involvement has been used by the SCSI as a prototype for several other restoration programs and projects. Nonetheless the rangeland system is still unsustainable since farmers have not adopted SLM approaches as expected. This lack of adoption was likely due more to system errors and gaps than to the perceived “silo mentality” structure of the governance system than to the sheep farmers themselves [140]. The Icelandic case clearly shows the complexity of rangeland restoration and could thus be used as a prototype for building up restoration strategies for degraded rangelands in other locations.

5. Forests

Forests provide livelihood opportunities for local populations and contribute to food security, climate change mitigation and adaptation, as well as the protection and enforcement of natural capital [146]. Tree planting is only one of many strategies in restoration projects [147]. The State of the World's Forests published by FAO [148] highlights socio-economic benefits from forests worldwide which include benefits derived from the use/management of forests, promotion of sustainable non-timber forest products, and job creation through public forest programs. Therefore, the success of forest restoration efforts and their sustainability have to be based on multiple strategies tailored to local conditions and needs.

5.1. Afforestation and Sustainable Management of Natural/Planted Forests in Drylands

Rehabilitation and management strategies developed for moist forests may not be suited for dry forests. The high proportion of small-seeded wind dispersed species, the high sprouting ability, and the relatively simple structure and low diversity of dry forests should be taken into consideration when devising rehabilitation plans [149].

Forest restoration strategies include rehabilitation to restore species/communities and ecosystem processes and reclamation to revegetate severely degraded landscapes [150]. Afforestation permits the reestablishment of connectivity and avoids forest fragmentation problems [142]. A set of strategies to facilitate the success in revegetation options can be: (1) planting legacy trees species, isolated, in a linear plantation or clustered to function as seed dispersers and habitat and to improve the microclimate; (2) restoring critical sources for wildlife like riparian areas; (3) protecting the water lines; (4) protection soils and promoting soil fertility; (5) planting native species as succession facilitators to enrich the ecosystem; (6) eliminating invasive species; and (7) reducing fire susceptibility. Anthropogenic forests rarely have fallen and decaying woody debris, which create important habitats, so it may be necessary to introduce a certain degree of deadwood structures in restoration projects [151].

In some cases, assisted natural regeneration and area exclosures enhance natural recovery by protecting rehabilitation sites from human and animal disturbances, increase plant and animal diversity, increase vegetation biomass and coverage, and improve soil physical and chemical properties [152,153]. On heavily degraded sites, enrichment planting of late-successional or rare species is necessary in order to speed up the recovery process [154].

For highly degraded dry forests active restoration approaches, such as framework species, maximum diversity, multi-species planting, and nurse tree methods may be more appropriate than passive restoration methods. However, active restoration methods are costly and require sufficient ecological knowledge for effective implementation [155]. Because of the relatively slow growth rate of dry forests active restoration strategies may require long-term commitment to be successful [156].

A well-known case of afforestation occurred in Cape Verde [157] (Table 4). In these Islands, only 3000 ha were considered forest land in 1975, but by 2011 there were over 90,000 ha of afforested land, as a result more than 20% of the country is now afforested. Some site-specific practices were implemented to control surface runoff such as half-moon structures called *caldeiras* made up of contour furrows and bench terraces with stone walls and small dams to prevent gullies. This project utilized a top-down approach, where the state conducted the afforestation and there has only been a moderate trend towards spontaneous maintenance of the afforested areas. Socio-economic disadvantages such as increased costs of agricultural products and economic inequity between inhabitants because it reduced the percentage of land for agricultural production, may be overcome with the long term integration of the community into the forest's management.

Table 4. Case studies on forest restoration and management practices and their multidimensional impacts on biodiversity, water availability, soil, and socio-economic improvements. Key: SOM: soil organic matter; ⊕: increase; ⊖: decrease; ⍓: improvement.

Strategies and case studies (e.g., country & references)	**Impacts on:**				
	Biodiversity	**Water availability**	**Soil**	**Economic remit**	**Social impacts**
Afforestation and Sustainable management of natural/planted Forest in drylands. *Management/ technical measures ensuring sustainable use of natural forests or sustainable production of woody and non-woody products.*					
Afforestation, Cape Verde: [157]	Promotion of vegetation species and varieties	⊕infiltration	⊖soil erosion/runoff	⊕production (wood, fodder)	⊖downstream flooding/siltation and reduced damage on fields
Assisted cork oak regeneration, Morocco [158]		⊕groundwater level	⊕ground cover ⍓soil structure ⊕SOM ⊕biomass ⊕soil moisture ⊖crusting		⊕aesthetic value of the landscape
Agroforestry: integration of crops and animals with woody perennials. *Land use systems and practices in which woody perennials are deliberately integrated with agricultural crops and/or animals on the same land management unit.*					
Chagga homegardens, Tanzania [159]	⍓biodiversity and soil life	More effective use of available water	⊕ground cover ⊖water/wind erosion ⊖runoff ⍓micro-climate ⍓biological activity	Crop diversification Higher combined yields (trees, crops and livestock)	Community institution strengthening ⍓aesthetic value ⊖production risks, ⊖vulnerability ⊖ conflicts due to reduced negative off-site impacts ⍓food and water security ⍓livelihood and well-being
Grevillea agroforestry system, Kenya [160]	⊖pressures on native forests	Access to clean drinking water			
Parkland agroforestry system, Burkina Faso [161]	⍓biodiversity and soil life	⍓water availability and quality	⊕SOM/fertility ⍓soil structure	⊕cash income Provides products year around ⍓employment	
Farmer managed natural regeneration, Niger [162]	⍓biodiversity and soil life				

Similarly, the Moroccan state promoted cork oak (*Quercus suber*) afforestation of the degraded Sehoul forest which is owned by the government but managed by local communities [158] (Table 4). Establishment activities included soil preparation, weeding, planting, watering, fencing, and enclosure periods lasting a minimum of 6 years. Ecological advantages were obvious and slight benefits for cork, wood, and fodder production positively impacted the socio-economic conditions of local populations. However, this area is populated by poor farmers who are strongly dependent on forest resources resulting in increased grazing pressure on neighboring areas. Early involvement of local communities in the decision making process is considered important for the long term success of afforestation projects.

As rehabilitation is a long-term effort, success of dry forest rehabilitation depends on clear land tenure as well as well-defined and secure property rights for land and trees [163]. Local communities who are affected most by rehabilitation projects should participate from project conceptualization to implementation and management [148]. Rehabilitation operations should also consider local peoples' short- and long-term needs and value systems in order to sustain their participation and interest [164,165].

5.2. Agroforestry: A New Name for a Set of Old Practices

According to the World Agroforestry Centre, agroforestry is defined as land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit. Properly managed, agroforestry systems can be very beneficial for land users and their environments. Agroforestry system types include: silvopasture, alley cropping, multilayer tree gardens, homegardens, multipurpose trees on croplands or shelterbelts, where widely spaced rows of trees are planted between annual crops or windbreaks and buffer strips in different ways [166].

The need for multifaceted measures to achieve successful rehabilitation of forested areas can be seen in the human-managed homegardens of Tanzania. The perpetuation of traditional *chagga* homegardens in sloping regions near the Mount Kilimanjaro Region is under risk. This century-old transformation of native forest into a complex multicropping system integrates numerous multipurpose trees and shrubs that provide fodder, fuel, and food and cash crops such as coffee, bananas, taro or yams, and stall-fed animals in a continuous and diversified production over the year [159] (Table 4). The hill slopes (>16%) involve maintenance activities that are being abandoned due to labor shortages that disrupt intergenerational knowledge transmission. In order to maintain these homegardens several active rehabilitation strategies are being carried out: planting new cash or food crops considering the appropriate spacing for each species, manuring crops with dung from livestock, lopping fodder trees or shrubs, maintaining and improving irrigation furrows and terraces, and improving apiculture amongst others options. Strong long-term community involvement and improvement of advisory services is needed for the success of such rehabilitation.

Assisted tree regeneration in Parklands in semi-arid West Africa is also a multipurpose agroforestry system. In Burkina Faso saplings are retained from natural regeneration, planting is improved using material through the selection of vigorous shoots, and grafting and pruning are used [161] (Table 4). The protection from animals is achieved by dead or live fences. Tree species are baobab (*Adansonia digitata*), tamarind (*Tamarindus indica*), shea nut or *karité* (*Vitellaria paradoxa*), *néré (Parkia biglobosa*) and *Faidherbia albida*. Due to the use of various layers/storeys, these parklands improve crop diversity by growing mixed but compatible crops of different heights in the same area; they also protect soils and support ecological functions and services including the creation of a favorable micro-climate.

Boundary planting of diverse tree species to mark property boundaries can also be used to supply fuelwood and building materials, provide shade, and for ornamental value. The trees may be combined with grass or shrub species or other integrated land management measures. As a result, boundary planting is effective for improving soil cover, soil fertility and moisture, reducing wind velocity, and preventing soil loss as well as enhancing biodiversity. In a case study described by Mwaniki [160] in Embu, Kenya, additional socio-economic benefits of boundary planting include the provision of mulching materials, fodder, timber and fuelwood, enhancing stakeholder interaction, and employment in the community. Tree species selected for planting must be easily established, resistant to pests and diseases, and tolerant to a wide range of climatic and soil conditions. In the subhumid and rolling to hilly region of Embu, trees in boundaries are mainly silky oak (*Grevillea robusta*) plantations mixed with annual crops as boundaries to create "open" forests with multi-storey layers. In addition to the on and off-site benefits already mentioned, plantations prevent deforestation of native forests since alternative sources of fuel and timber are provided.

Naturally occurring seedlings in forests can be protected and managed by local farmers to promote agroforestry. This so-called farmer managed natural regeneration is a simple, low-cost, and multi-benefit method of re-vegetation practiced in semi-arid Niger [162] that provides multiple benefits to people, livestock, crops, and the environment (soil and water conservation, erosion control, increased biodiversity, *etc.*, see Table 4). In semi-arid Niger the most valuable species for land users are *Faidherbia albida; Piliostigma reticulatum* and *Guiera senegalensis*. The ideal density, when grown with cereal crops, is between 50 and 100 trees per hectare. The tallest stems are selected by farmers and side branches are removed. Pruned leaves are left on the surface where they reduce erosion and are then eaten by termites, cycling the nutrients and carbon back to the soil. Since the 1980s, this practice has expanded spontaneously through more than 50,000 km^2 in Niger, with minimal external assistance. Importantly, the increased wood, crop, and livestock production has led to increased food security and improved quality of life.

5.3. Forest Fire Prevention/Restoration

Thousands of hectares of forest landscapes burn every year, with serious consequences to the environment [167]. It is well known that fire is essential in Mediterranean landscapes for ecosystem function and some species have reproductive mechanisms that require burning or high temperatures [168]. However, over the years, the function and structure of forest ecosystems has changed, and nowadays forests are more susceptible to wildfires, which are more severe and larger than fires in the historical records [169]. Preventive measures include the reduction of the density of trees and understorey vegetation removal, particularly if cattle have been removed, or the implementation of strip networks for fuel management, e.g., in Maçäo, Portugal, Coelho *et al.* [170] (Table 4) describe the establishment of discontinuities in the vegetation cover in forest areas using linear strips with sparse vegetation and also water bodies, agricultural land, or rocky outcrops. There are some potential social conflicts when private land is affected by this measure, and also erosion problems in the strips that must be avoided by seeding, the use of mulching, or low intensity pasture. Grazing activities can contribute to the maintenance of these strips but collaboration between local and national authorities for providing equipment, labor force, and funds is considered a key point for long-term efficiency of such preventive practices.

Several post-fire restoration techniques are used in Mediterranean Europe and their success depends on site specific conditions [171–173]. Some of the main actions used in forest restoration are intended to achieve compositional and structural conditions resistant and resilient to fire [174]. This is accomplished by altering species composition (e.g., types, number, and sizes of individual structural elements including trees, bushes, and grasses), or by eradicating monocultures (e.g., dense ponderosa pine or eucalyptus plantations), or by promoting a new partial or complete understorey, removing competition, and enhancing growth conditions.

Care must be taken to avoid soil degradation, as typical post-fire operations involving vehicle traffic, understorey removal, or salvage logging, may hinder the recovery of native tree species and promote invasion of alien species [175]. In other situations it may be necessary to consider age diversity and structural heterogeneity in the forest composition, and restore it if needed [150]. Therefore, forest density reduction may create the desired forest structure to avoid wildfires but it may fail to achieve the desired ecological function [169].

Restoring semi-arid forest landscapes often requires soil recovery actions to provide a good base for plant establishment and growth [176], however, there are still some controversies regarding the methods to achieve this restoration. Practices such as salvage logging [177,178], cleaning ashes operations, and the use of amendments [179] are typical semi-arid forest soil restoration practices. There are no disagreements, however, on the necessity to improve soil water retention capacity [180] and prevent erosion after fire [168,181].

6. Sand Dunes Management

Coastal zones are particularly rich in environmental, social, cultural, and recreational services. Intensive pressure from human activities in coastal environments makes these areas one of the most demanding ecosystems to be monitored and re-considered for restoration and sustainable use [182–184]. Climate change and subsequent sea level rise, and continuous population increase in coastal zones will surely impact not only the resilience of coastal systems but also affect strategies of adaptive management that aim at maintaining ecosystem goods and services [62,185]. In order to understand if a coastal ecosystem is self-sustainable and resilient in the long run, long term monitoring is required [183], which is usually difficult and expensive to accomplish. A more integrated approach is needed to sufficiently describe these dynamic geomorphic-biologic dependencies and the feedback between processes and responses [186]. Particularly, coastal dune intervention activities include mainly the reshaping of dunes and the recovery of sediment dynamics and dune stabilization by controlling invasive species of plants and animals. In terms of restoration methods, Lithgow *et al.* [183] noted that there is no best way to restore a dune. The formation of dunes could be accomplished through beach nourishment, by providing the necessary sand volume and space for the dunes to develop, however in this case, maintenance is necessary for the preservation of dune integrity and time is needed for dune species to colonize [187]. However, the restoration of vegetation and morphology can last up to ten years [188] and be expensive.

Increased vegetation planting can also assist the stabilization and development of coastal dunes, as vegetation can trap and stabilize sediments, reduce the wind intensity, and provide habitat. It is, however, important which plant species are used, as native species will have higher survival rates and are easier to propagate, harvest, store, and transplant than non-native ones in general [189].

An example of sand dunes restoration occurred along the Senegalese coast from Dakar to St. Louis that suffered repeated droughts in the 1970s.The region was degraded by overgrazing and deforestation [190] as a result, dunes advanced at a rate up to 10 m per year through villages and agricultural areas. A large scale rehabilitation project was carried out between 1970 and 1990 that included the establishment of the non-native casuarina tree (*Casuarina equisetifolia*) in these poor sandy soils which cover and area of 9700 ha. Multiple positive impacts have been described apart from the protection of villages from advancing dunes. Ecological benefits resulted from wind erosion control and improvement of soil and biomass conditions, and further direct economic gains are related to wood, fodder, and mulch production. Further indirect economic gains arise thanks to improved fisheries and increased recreational activities. Remarkably, land users claim that without this forested belt they would not be able to live in the area due to harsh environmental conditions. Currently land users and authorities are facing the challenge of natural regeneration of the casuarina tree since senescence occurs after 30–50 years. This may however provide an opportunity to reintroduce local species for afforestation.

7. Discussion and Conclusions

Appropriate land management is crucial to achieve economic growth, improved biodiversity, create sustainable agricultural systems, attain food security, eradicate poverty, address climate change, and improving water availability [191]. Links between ecosystem services and best soil and water management practices have been made in the case studies present in this review. The majority of cases discussed refer to sustainable use or restoration or rehabilitation of fragile ecosystem services in areas that have harsh environments, particularly in drylands. Sometimes dry environments suffer added difficulties because local communities often live under economic constraints and have little capacity to adapt to the extreme and fluctuating climatic conditions that lead people to overuse natural resources.

Traditional WH techniques to save water are crucial in these areas. Positive effects of such techniques must not be underestimated in providing food security in most of the developing world, where smallholder farms play a vital role in sustaining their families and communities. In Africa and Asia approximately 1.5 billion people live in smallholder households and they provide up to 80% of the food supply to their families [192]. The challenge for adoption of WH techniques lies in the necessity to convince the population about the off-site benefits, which can be achieved by an integrated catchment approach.

Agrarian systems including croplands and rangelands are complex social-ecological systems that in order to function efficiently, require not only ecological and bio-physical understanding of all issues involved but also well-structured policies and coherent and transparent governance systems and cooperative actors. The long-term ecological success of restoration or the effective upscaling of SLM will always depend on a joint strategy for all proposed management activities, accepted by the majority of concerned stakeholders. From the analysis of the case studies gathered in this review it is apparent that adoption of sustainable management practices is usually lead by imitation. In order to facilitate upscaling of SLM, policies have to facilitate the spread of information, support capacity building, and encourage local communities' participation. Many examples cited in this study show a significant increase in production, jointly with other benefits related to biodiversity, soil, water, and human wellbeing. Most examples refer to smallholders that manage low productivity systems and in many cases despite the crop yield or crop quality long-term benefits. Conservation agriculture or other SLMs will not be adopted for the long-term without solid conviction of land users. Otherwise smallholders will quickly revert to traditional non-sustainable practices as soon as the subsidies finish or when there are no short-term profits [193].

The need for new crops and pastures are still reducing forest area globally. Approximately 10% of agricultural area expansion globally has been from deforestation [194]. Recent studies argue that the maximum rate of cropland expansion has been reached and as a result forest ecosystems will not decrease in the future [195]. In the meantime, as mentioned, approximately 30% of natural forests are undergoing some degree of degradation, so restoration particularly after fires are of critical importance. Forest restoration is a long-term process, especially in drylands. In order for forest restoration practices to be accepted and supported by local communities appropriate incentives focusing on multipurpose restoration or rehabilitation practices, including agroforestry, must effectively change attitudes from short-term choices to long-term SLM practices. In fact, productivity of agroforestry systems has risen by avoiding monocultures and increasing its role in rehabilitating landscapes [196].

Coastland and dune restoration is marked by special features related to the high pressures that these ecosystems are experiencing from population pressure, possible sea level rise, and the high capital investment required to combat their degradation. Restoration projects are usually public and follow top-down approaches. Such approaches have to be linked to community participation throughout the entire process. Coastal environments are transitional areas between two different ecosystems and they experience naturally dynamic processes in both spatial and temporal dimensions that are difficult to manage and predict and thus they require long-term monitoring and social involvement to achieve successful sustainability.

Stakeholder involvement can improve the decision-making process by integrating new ideas and local knowledge into the process, thereby increasing the quality and appropriateness of decisions [197]. According to Schwilch *et al.* [198] in order to adequately reflect economic, environmental and social aspects in assessing sustainability, a participatory multi-stakeholder collaboration in SLM projects is more likely to be successful and to establish acceptability if local stakeholders are involved as early as possible in the planning and management process, fostering a sense of ownership of the project goals [199]. Often local perspective is dominated by conflicts of interest and certain mistrust of recommendations from scientists or government consultants. The roles and interests of key local stakeholders, as well as the motives that drive their decisions must be carefully examined for successful implementation of SLM. Some instruments like the Delphi method, based on the assumption that group judgments are more valid than individual judgments [200], helps to integrate stakeholders' and decision-makers' priorities. Table 5 summarizes recommendations for facilitating upscaling of land management and restoration.

Table 5. Recommendations for facilitating upscaling of land management and restoration. The order is arbitrary, each region or country can have distinct priorities.

Scope	Recommendations
Global level:	Endorse scientific panels to advise international policy organizations. Use international organizations to increase awareness of the relations between different aspects of SLM that favor land care, food and water security, climate change mitigation, and biodiversity.
National level:	Maintain policies that promote education and support the spread of knowledge on SLM. Promote the involvement of national television and radio media to address environmental issues related to land management. Subsidize SLM and restoration projects until land users perceive benefits in the medium/long term (e.g., economic aids to mitigate any increases of labor costs due to SLM practices). Create land tenure arrangements to motivate land users to invest in SLM practices. Facilitate availability of funds for projects when including both biophysical and socio-economic aspects. Facilitate and finance the long-term monitoring of biophysical and socio-economic as well as on- and off-site impacts of SLM through research institutions.
Local level:	Provide training, material, and technical assistance. Provide appropriate resources to obtain long-term monitoring of SLM results. Provide appropriate resources for medium to long-term monitoring of social acceptance of SLM. Ensure that implementation follows the principle "the simpler, the better"; complicated measures, high investment costs, or the need for specific or heavy machinery can hinder the adoption of SLM. Promote social cohesion to solve catchment-scale environmental problems. Ensure early involvement of local communities in the decision making process for the long-term success of SLM and increase of trust between stakeholders. Recognize and support local practices and innovation before promoting new external practices. Encourage and fund local research.
Academia:	Encourage the participation of scholars in scientific networks of knowledge. Promote the need to study the watershed or landscape perspective as integrated socio-ecological systems. Involve scientists in panels of interdisciplinary mutual learning with other stakeholders such as extension agents, NGOs, land users and policy makers. Encourage scientists to participate in programs for educating trainers. Encourage academic recognition of policy briefs, leaflets, or documents targeted at civil society. Promote research projects that: • assess and demonstrate the economic, ecological, and socio-cultural benefits of SLM, particularly for croplands and rangelands; • evaluate possible conflicts of interests or requirements of different parts of social systems *i.e.*, losses and gains derived from particular management or restoration not to generate inequity between local stakeholders. Produce other outcomes apart from scientific papers, such as leaflets, videos, reports targeted to a wider audience.

Policy is crucial in successful SLM because governments can promote well informed land use decisions. Policy instruments include local, regional, and international legislation and regulations, but probably the most effective policy tool for the implementation of SLM is public education. Lamentably, the major reason for insufficient implementation and adoption of environmentally sound land management is the lack of efficient channels to transmit knowledge and technology between environmental science and policy [201,202]. To achieve effective communication of scientific knowledge to policy findings must be interdisciplinary and have cross-sector approaches [203].

There is also a controversy in the scientific community with regard to options for development models. While some scientists support sustainable production globally, others defend the protection of natural habitats and the intensification of the remaining land to achieve higher yields [204].

In addition, biophysical and socio-economic variability at local scales impede the application of universal or simple rules for sustainable land management. There are technical problems that must be solved at local levels. To overcome these technical issues traditional knowledge, adapted to climate, soil condition, topography, level of mechanization, population density, and workload must be considered. Thus the importance of establishing environmental indicators to monitor degradation, rehabilitation, and sustainability of ecosystems and conditions [205] as well as prediction models that consider both ecological and human variables is clear [206]. The development of indicators that represent an integration of economic, social, and environmental dimensions of dryland development is a major challenge, and requires a robust foundation [207]. The team of researchers involved in this review supports the development of common but flexible indicator sets to assess long-term progress towards the environmental, economic, and social benefits of SLM practices. Considerable efforts are required to support local research, as this is one of the most cost-effective ways to mitigate global risks of land degradation.

Despite scientific knowledge usually being site specific, micro-scale, short term, and frequently disseminated mainly only amongst peers, some cases presented here have demonstrated the capacity of many efforts that have been able to surpass these drawbacks. The examples presented here have shown that networking and mainstreaming into an organized international database, such as WOCAT, which greatly enhances the global assessment of dryland conservation approaches and technologies has been beneficial if not essential. For these cases we acknowledge that the most frequent weaknesses observed for SLM adoption are usually the low awareness of stakeholders and the strong dependence on external subsidies and technical support. Contrary to the frequently mentioned lack of sufficient and integrated monitoring and assessment of the UNCCD [208], this review shows that biophysical information has been established in many cases, but social capital is lacking, even though it is an important requirement for the sustainable adoption of behaviors and technologies. However, continued monitoring and evaluation through land users and researchers is required in order to prove and acknowledge the multifaceted benefits of sustainable land management.

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