Sustainable Land Management Paradigm: Harnessing Technologies for Nutrient and Water Management in the Great Lakes Region of Africa

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1 Introduction

Land remains a critical resource in the provision of goods and services for livelihoods. Land is defined as a terrestrial system that comprises of the natural resources (such as soil, vegetation, climate, biota, geology, topography, water and air), the ecological processes, human settlement and the infrastructure, all operating within a system (FAO 2008). Despite its critical role, land resources are currently highly endangered due to rapid degradation that is orchestrating poverty, food and energy insecurity; and malnutrition particularly in the fragile ecosystems and sociocultural systems of the world. The human population, which is predicted to increase from 7.7 billion to about 9.7 billion by 2050, is one of the major threats to the integrity of land (UN DESA 2019). Currently, about 5 billion hectares of land (43% of earth's vegetative surface) is degraded, with a raging degradation rate as high as 10–12 million ha yr^{-1} (Thomas et al. 2018). In Africa, about 75% of the total arable land is degraded, with about 4–7% in Sub Saharan Africa (SSA) severely degraded (Orchard et al. 2017).

Degraded land is a major limitation to livelihoods for millions of people in SSA as land is their daily work table for income. The problem has been aggravated by climate change and rapid changes in technologies, which have led to increased floods, drought and community conflicts. It is now a global agenda that action oriented interventions be effected to counter land degradation and boost productivity. Sustainable technology applications that are characteristic of the right

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methods, techniques, skills and management approaches are vital for inclusion in the planning processes.

Sustainable Land Management (SLM) is an approach that can respond to degradation challenges with support of verified relevant technologies. It considers integration of soils, crops, livestock, water, energy, finance and human resources (WOCAT 2016). WOCAT (2016) clearly describes SLM as the use of the land resources, which include soils, water, animals and plants, for the production of goods and services to meet changing human needs, while simultaneously ensuring long-term productive potential of these resources, without compromising environmental health. The adoption of SLM has proved impactful on all ecosystem functions and services (Terefe et al. 2020). The benefits of SLM range from high and stable crop yields, regulated surface runoff and soil loss rates, reduced nutrient losses, which consequently result in increased landscape resilience, reduced production risks, improved food security and livelihoods (Branca et al. 2013; Martínez-Mena et al. 2020). The drivers of effective and efficient SLM processes are appropriate soil and water management processes, and these (codenamed indigenous technologies) have been practiced by millions of farmers for many years, though largely in the survival mode (Liniger 2011). Against this backdrop are emerging (improved) technologies with ability to catalyze meaningful sustainable land management. Limited empirical assessment has been made of these indigenous and improved technologies in the context of their adoption for sustainable land management within the sociocultural settings of the target great lakes communities. This paper reviews the existing soil water and nutrient management measures as a guide for out scaling of high potential SLM technologies and practices to achieve sustainable livelihoods in the great lake's region of Africa.

2 Sustainable Land Management: Definition and Pillars

There are several definitions of SLM that are tailored to sustainable use of natural resources to secure improved livelihoods. FAO Terr Africa defined SLM as the 'adoption of land use systems through the use of sound management measures or practices, and enabling land users to achieve maximum social and economic benefits from the land; while maintaining the ecological functions of the land resources (FAO 2008). World Bank (2006) defines SLM as a knowledge based procedure that helps to integrate land, water, biodiversity and environmental management, with the goal of meeting human needs while sustaining ecosystem services and livelihoods. Smyth and Dumanski (1995) earlier defined SLM as a combination of technologies, policies, and activities that are aimed at integrating social economic principles with environmental considerations but maintaining and enhancing productivity, reducing risks and enhancing soils buffer capacity against degradation; protecting natural resources such as water and soil from degradation; and aiming at socially acceptable and economically viable measures easily accessed by communities. Hurni (2000) defined SLM as a system of technologies and/or planning that aims at integrating ecological, socio-economic and political principles in land management for agricultural and other purposes to achieve intra- and inter-generational equity. WOCAT (2016) more recently defined SLM as the ‘use of land resources which includes soil, water, animals and plants, for the production of goods to meet changing human needs while simultaneously ensuring the long-term productive potential of these resources and maintaining their environmental functions. The element of integration is emphasized across the spectrum of definitions, aiming at preserving land resources including nutrient and water resources. These resources remain the drivers of food, fibre, forage and fuel production, all of which are critical in sustaining livelihoods for millions of people.

Sustainable Land Management mitigates possible depletion of nutrients, moisture stress, soil loss and overall decline in land productivity. Water productivity is enhanced at field and catchment levels by ensuring water availability, storage capacity and quality. The mitigation interventions are in line with the widely defined pillars of SLM (Gessesse and Zerihun 2017). According to Gessesse and Zerihun (2017), the pillars of SLM include both agro-ecological and socio-economic factors; namely (i) income (when farm household income is evident), (ii) land productivity (when high yields are evident), (iii) environment protection/conservation (when resources are preserved in right quantities and quality), (iv) viability (when management options are locally adoptable and implementable), and (v) acceptability (when social acceptance is evident). The application of SLM pillars has other impacts on land productivity including reduction in agricultural related risks when social response, environment and economic factors are considered (Emerton and Snyder 2018). The SLM approach enhances nutrient and soil carbon re-stocking, consequently minimizing soil fertility decline but also increasing water availability, especially in moisture stressed environment.

3 Land Degradation Impacts and Solutions Relevant in Water and Nutrient Management for Sustainable Land Management

Several processes of land degradation are widely reported and include nutrient decline, loss of soil organic matter, water and wind erosion, soil acidification, soil salinization, soil sealing, heavy metal contamination and many others (Henry et al. 2018). These processes affect water and nutrient cycles thereby affecting soil, water and plant relationships. Processes (causes and effects of degradation) that disrupt nutrient supply and water availability can lead to decline in soil health, loss in land productivity and degraded environment. Table 1 highlights the causes and effects of degradation commonly reported in the great lakes region; potential impacts of degradation on nutrient and water resources and suggestions for possible solutions. The analysis is based on the causes and effects of degradation widely reported

(Olupot et al. 2019; Kiage 2013; Terefe et al. 2020). Some of the interventions are being promoted to improve water and nutrient management although challenges still exist in adoption due to the differences in the type of landscape and social-cultural establishment.

Although some of the interventions have been promoted in the Great Lakes region (Table 1), there is increasing evidence of less adoption by several farmers which is a threat to SLM. The low adoption of SLM techniques is a function of many factors including the social-cultural factors. The approach remains less adopted among land users in the region not because of lack of scientific technologies but because of lack of incentives and measures to sustain the indigenous approaches. The success of SLM demands that land users remain mindful of competing investment options that result in higher returns. If the returns from SLM are not profitable, there is always a shift in plans to choose other quick trade and businesses alternatives (Tenge et al. 2004). Other land users resort to rapid shift from one land use to another when there is decline far below the sustainability threshold for production. Therefore, SLM options relevant to water and nutrient management require an approach that considers a range of factors that influence land management decisions. A people centered management approach backed by existing local and national (government) institutions is critical. Emerton and Snyder (2018) denoted that interventions with less regard of land users can never address land degradation. The inclusion of the end-users is a critical step among the pillars of SLM in ensuring sustainable application of technologies.

4 Practices and Technologies for Sustainable Nutrient Management and Soil-Water Conservation

Land degradation can be addressed by applying practices and technologies that are in line with the pillars of SLM so as to achieve high land productivity, environmental conservation and income. The World Overview of Conservation Approaches and Technologies (WOCAT) has proposed various principles that support practices critical for soil water and nutrient management (Liniger 2011). The principles promoted by WOCAT include water-use efficiency and productivity, soil fertility, plants and their management, and micro-climate management (WOCAT 2016). Most of these principles resonate with practices and technologies vital for SLM.

Several SLM measures are being promoted in the region, all targeting the conservation of soil and water for increased land productivity. These practices include resource conserving measures such as organic farming, eco-agriculture, conservation agriculture, agroforestry, integrated nutrient management, integrated pest management, integrated livestock systems, water harvesting and aquaculture. These practices have demonstrated impact on soil water and nutrient management by reducing on unproductive losses of water, replenishing nutrient stocks,

Table 1 Land degradation, impacts and potential solutions relevant to water and nutrient management in the great lakes region of Africa

Selected causes (with example of effects) of land degradation	Impacts on water and nutrients	Potential solution(s)
Limited planning (misuse of land)	Loss in water quality	Land use planning
Substandard agro-inputs (nutrient depletion)	Limited supply of nutrients	Testing fertilizer quality
Inadequate organic material use (SOC depletion)	Limited capacity to restock organic carbon	Promote organic material regeneration
High surface runoff (soil loss/siltation)	Bare land and shallow soils with low water retention	Soil loss control
Rapid land use changes (high greenhouse gas emissions)	Nutrients lost through volatilization	Proper land use
Surface vegetative cover depletion (evapotranspiration)	Water loss from crop field	Use of conservation agriculture
Over-cultivation (degradation of soil structure and carbon)	Low nutrient retention capacity	Conservation tillage
Flooding (water logging)	Excess water and leaching of nutrients	Improved water management e.g. Ridging
Desertification (biodiversity loss)	Permanent loss of water and biota	Restoration with desert tolerant vegetation
High soil temperature (loss of soil biota and moisture)	High evapotranspiration	Use of soil covers
Inherent salinity/mineral weathering (salinization)	Limited nutrient availability	Adopt tolerant varieties
Uncertain precipitation (decline in ground water level)	Soil moisture stress	Apply soil water conserving measures and supplementary irrigation
Leaching (fertility decline)	Loss of mobile nutrients	Apply slow releasing fertilizers with soil conservation measures
Animal overstocking/overgrazing (soil compaction)	Low water infiltration capacity	Optimize livestock numbers per land area
Volatilization (nutrient loss)	High loss of volatile nutrients	Minimize soil disturbances
Non-judicious use of agro-chemical (toxicity)	Decline in soil biota which subsequently affect nutrient release processes	Proper use of agro-inputs
Acidity (non-responsive soils)	Low availability of nutrients	Restoration of soil quality through liming
Alkalization (non-responsive soils)	Unavailability of some nutrients	Using tolerant crop varieties

(continued)

Table 1 (continued)

Selected causes (with example of effects) of land degradation	Impacts on water and nutrients	Potential solution(s)
Massive export of plant materials (loss in nutrient stocks)	Negative nutrient balance from farmers' fields	Increase residue retention
Burning (loss of nutrients)	Permanent loss of nutrient stocks	Stop burning of residues
Pollutant depositions (soil contamination, microbial death)	Unavailability of nutrients	Improved policies on soil protection
Wind erosion (depositions and enrichment)	High pollution of soil water	Monitor depositions and effects
Deforestation (bare land and soil loss)	Loss of nutrient stocks and high surface water runoff	Encourage tree planting
Social economic challenges		
High price of inputs (limited use)	Inability to purchase fertilizers to replenish nutrients	Fertilizer subsidies
High cost of water equipment (inability to access water resources)	Improper use of available water	Reduce taxes on water storage and supply infrastructure
Weak policies (poor soil management)	Misuse of agrochemicals	Policy guide on chemicals use
Poverty (lack of capital)	Inability to apply fertilizers or water conservation materials	Revolving funds
Limited land ownership (low confidence in land use and management)	Limits use of soil water conservation measures	Secure land ownership
Political instability (misuse of land)	Affects plans for sustainable soil water conservation measures	Promote political dialogues
Rapid urbanization (contamination and pollution)	Pressure on water resources	Effective urban planning

Source Authors based upon Olupot et al. (2019), Tully et al. (2015), Kiage (2013), Sanginga and Woomer (2009), Musinguzi (2017)

increasing storage and reducing pollution (Motavalli et al. 2013; Bossio et al. 2010). The majority of these SLM practices have been refined with the new approach for effective nutrient and water optimization, in a system defined as precision farming. In this approach, the land use system is steered by site specific management interventions. The land use measures are controlled by real-time data on soil and landscape variability to guide precision farming processes for increased efficiency in water and nutrient application. Some farming systems apply drones supported by GIS mapping and geo-statistics to accurately diagnose the constraints and provide interventions. The precision management approach is still at infancy in many African countries but it is a critical tool for optimizing resource use for high yields and water productivity, at farm scale and landscape levels. Besides, site specific measures with precision, are central in closing the yield gap in areas that produce below their potential, so as to make substantial impact on world food security (Tilman et al. 2011). The yield gap can be tackled with some of the technologies or practices highlighted in soil water conservation and nutrient management.

5 Technologies for Sustainable Nutrient Management

The implementation of SLM requires that nutrient management options are evaluated to guide land users establish affordable, acceptable, accessible and result-oriented technologies and practices that would result in highest yields. In this section, different management and technology options are categorized based on expertise and available literature in the context of material availability, application skills and sustainability (Table 2). The component of material availability and application skills is herewith represented as not available, moderately available and most available. The sustainability component is described in the context of resource constrained land users (mainly famers) in the great lakes region of Africa. All nutrient management measures are categorized basing on the pillars of SLM with emphasis on the social-cultural factors that influence adoption of a technology. Those that are common, affordable and acceptable (are represented as ++++); those that are less common, modestly affordable and acceptable (are represented as +++); those that are not common, not affordable and may not be acceptable (are represented as +). The analysis provides information on existing capacity in the use of nutrient management options and the use of strategic interventions in terms of increasing material production, skilling strategies and policy measures to enhance adoption. The projections are tailored to smallholder farming systems that are usually resource constrained with limited capacity to establish some of the best-bet land management technologies.

Table 2 reveals that most smallholder farming systems (that are resource constrained) have major challenges in accessing most of the sustainable nutrient management measures. Some nutrient management interventions are limited by skills and materials in an effort to achieve sustainable land management. This poses a threat to the current state of soil and land management, food, forage, fiber and fuel security and livelihoods in the region. There is a limited use of a range of agro-inputs that replenish depleted nutrients although organic related inputs remain locally available and easily accessible. Soil fertility management technologies and practices that are recommended are rarely practiced by majority of land users. The main limitations to the use of inputs is the lack of skills and the capacity to purchase inputs that are vital in advancing scientific innovation in SLM. As such, there is

Table 2 Sustainable nutrient management options commonly applied in the Great Lakes Region of Africa

Nutrient management options	Availability of materials and skills	Likelihood for sustainability (on adoption)
Inorganic fertilizers		
Mineral (macro) fertilizers (blended fertilizers)	Not available	+
Mineral (macro) fertilizers (Granular/compound fertilizers) e.g. Urea etc.	Moderately available	+++
Micronutrient fertilizers	Not available	+
Foliar fertilizers	Moderately available	+++
Agro-minerals (rock phosphates, limestone, potash, gypsum, pyrite)	Not available	+
Pelleted fertilizers/slow nutrient release fertilizer	Not available	+
Soil conditioners (humates, vermiculite etc.)	Not available	+
Fertigation	Not available	+
Organic fertilizers		
Green manure (incorporating legumes, grass, shrub litter)	Available	++++
Organic residues (e.g. mulch materials)	Available	+++
Compost	Moderately available	+++
Liquid manure/plant tea	Not available	+++
Animal manure (from cattle, poultry, farmyard, goats, pigs)	Available	++++
Mycorrhyza inoculants	Not available	+
Factory-made organic fertilizers e.g. Neem fertilizers	Not available	+
Beneficial soil organisms (Bio-fertilizers e.g. inoculants, free living fixers)	Moderately available	+
Agro-industrial product waste	Not available	+
Nutrient fortified compost (e.g. Rock phosphate fortified compost)	Not available	+
Vermicompost	Not available	+
Nutrient management approaches and tools		
Soil analysis—laboratory tests	Moderately available	+
Plant tissue tests	Not available	+
4R fertilizer management protocol	Moderately available	+
Micro-dozing	Not available	+
Organic and inorganic inputs (Integrated Soil Fertility Management Packaging)	Moderately available	+++
Organic matter management protocol	Not available	+
Slow/synchronized nutrient release measures	Not available	+

(continued)

Table 2 (continued)

Nutrient management options	Availability of materials and skills	Likelihood for sustainability (on adoption)
Crop residual composting and management	Available	+++
Crop nutrient requirements computations	Not available	+
Local indigenous diagnostics	Available	++++
Use of nutrient balance calculators	Not available	+
Instant soil testing kits	Moderately Available	+++
The fertilizer optimizer tool (fertilizer calculator)	Not available	+
Decision support systems applications	Not available	+

Source Authors based upon Sanginga and Woomer (2009), Bekunda et al. (2010)

need for a deliberate policy and intervention to promote management measures including the right use of inputs, adopting the right technologies, and practices that can promote improved land management.

6 Physical, Biological and Agronomic Technologies for Soil and Water Conservation

Optimal soil and water management is one of the critical components for boosting land productivity for high income and improved livelihoods. Global projections show that there is need to optimize water use, if smallholder farming systems are to overcome drought related constraints and food insecurity. It is projected that by 2050, more fresh water will be needed for agro-related services as the population increases and extreme events such as propagated drought increase (De Fraiture et al. 2007). Targeting technologies that enhance water productivity (more crop per drop) are critical in the planning process. This, however, requires identifying farmer friendly soil and water conservation measures that are in tandem with the pillars of sustainable land management.

Soil and water conservation options that reduce water loss by evaporation and runoff while increasing soil water storage were evaluated. Soil and water conservation measures common across the great lakes region were identified although these can vary with country depending on the inherent nature of the landscape and social-cultural factors (Mati 2006). For example, in Ethiopia, there are evidences of graded bench terraces, hill terracing, cut-off drain, grass strips, and contour bunds. Water harvesting measures such as underground tanks, ponds, open pans, spate irrigation are also common (Biazin et al. 2012). In Kenya and Uganda, common practices that retain water include conservation tillage, runoff harvesting, vegetative barriers, terracing, mulching, and trenches (Zhang et al. 2020). In Tanzania, some of the common soil and water conservation measures include ridging, bunded basins, pitting systems, surface runoff diverted from footpaths, and conservation tillage (Tenge and Hella 2005). Most of these countries in the great lakes promote increased water supply for use in various land use systems by promoting rainwater harvesting. Rainwater and runoff harvesting is important and there is notable link between water harvesting and soil water conservation since water can be conserved in situ and runoff can be stored in large area or storage unit for reuse.

A number of selected soil and water conservation measures were assessed while evaluating the likelihood for their adoption in resource constrained farming systems in Africa. It is important to note that in this evaluation, soil and water conservation measures are better implemented when: (i) the land ownership is assured; (ii) there is supply of labor; (iii) there are tools and materials for implementation; (iv) there are skills to support establishment; and (v) there are minimum funds to support the purchase and maintenance processes. Using a similar evaluation criteria for nutrient management (Table 2), social-economic aspect that form part of the pillars for sustainable land management (acceptability, affordability and viability) were considered (Emerton and Snyder 2018). The common, affordable and acceptable soil and water conservation measures (are represented as ++++), those that are less common, modestly affordable and acceptable (are represented as +++). Those that are not common, not affordable and may not be acceptable (are represented as +). For the component of availability of soil and water conservation support factors such as materials, labor and skills, these were categorized as available, moderately available and not available (Table 3). These were projected within the common setting of small-scale farming systems in Africa although research in SLM application remain inadequate.

The adoption of soil and water conservation technologies cannot be underrated in all efforts to ensure sustainable land management. These practices and technologies not only increase water infiltration capacity of the soil but also improve land and water productivity especially when soil fertility and rainfall distribution pattern are favorable (Sanginga and Woomer 2009). From the list of physical, biological and agronomic management measures, there is variability in how the communities in Africa are likely to adopt to the technologies. It is clearly evident that agronomic and biological soil and water conservation measures are more likely to be adopted than the physical structures that can be demanding (financially and otherwise) for the resource constrained farmers. However, physical soil and water conservation have always been very effective in minimizing soil loss and runoff compared to other soil conservation measures (Mati 2006). However, these require the use of more labor, specialized skills and resources.

Table 3 Physical, biological and agronomic measures common for soil and water conservation in the great lakes region of Africa

Soil and water conservation measures	Availability of materials, labour and skills	Likelihood for sustainability (on adoption
Physical measures		
Trench farming	Not available	+
Fanya Juu terraces	Available	++++
Fanya chini terraces	Available	++++
Stone lines/Rock bunds	Moderately available	+
Gully plugs	Not available	+
Bench terraces	Not available	+
Sloping terraces	Moderately available	+
Permanent planting basins	Not available	+
Hedge rows	Available	+++
Contour furrows and ridges	Not available	+
Diversion ditches/Cut-off drains	Available	++++
Road water harvesting drains	Moderately available	+++
Tied ridges	Not available	+
Zai pits	Not available	+
Trash lines along the contours	Moderately available	+++
Double dug beds	Not available	+
Half-moon furrows	Not available	+
Trenches/Anti-erosion ditches	Available	++++
Water tapping pits	Moderately available	+++
Stubble mulch tillage	Available	++++
Gulley control	Not available	+
Fish scale pits	Not available	+
Soil moisture retainers (Humates, hydrogel, biochar etc.)	Not available	+
Biological measures		
Surface mulching	Available	++++
Non-contour grass bunds/strips e.g. *Pennisetum purpureum*, *Tripsacum andersonii* etc.*)*	Available	++++
Contour grass bunds (planted)	Moderately available	+++
Natural grass strips	Available	++++
Crop residue retention in field	Available	++++

(continued)

Table 3 (continued)

Soil and water conservation measures	Availability of materials, labour and skills	Likelihood for sustainability (on adoption
Boundary tree planting/wind breakers	Available	++++
Agro-forestry/Multi-storeyed agro-forestry	Moderately available	+++
Silvo-pasture farming	Not available	+
Grass water-ways	Moderately available	+
Under-grazing (Paddocking)	Moderately available	+++
Surface vegetation cover	Available	++++
Maintaining of natural forest and trees	Available	++++
Right choice of land use type (Minimal soil disturbance)	Available	++++
Agronomic measures		
Deep tillage	Available	++++
Ripping	Not available	+
Dual purpose crop rotation	Moderately available	+++
Intercropping	Available	+
Zero/minimum tillage	Available	++++
Contour cultivation	Available	++++
Legume based cropping systems/cover cropping	Available	++++
Mixed cropping (various crops)	Available	++++
Alley cropping (trees and crops)	Available	++++
Relay cropping (double cropping)	Moderately available	+++
Contour planting	Available	++++
Early planting	Available	++++

Source Authors based upon Mati (2006), Liniger (2011), Emerton and Snyder (2018)

7 Integrating Soil Water and Nutrient Management Technologies

Soil water and nutrient management remain the central factors in increasing land productivity. The promotion of SLM technologies require that both nutrients and water are optimized. Recent advancements in agricultural land productivity have been pressing for integration science with the Integrated Soil Fertility Management concept widely promoted to respond to the principles of SLM (Vanlauwe et al. 2010; Musinguzi 2017). The combined use of organic, inorganic inputs, improved germplasm, soil water conservation and local adaptation, is emphasized with the ultimate goal of achieving high nutrient use efficiency and land productivity with minimal environmental effects. In SLM, the benefits of both nutrient and water use efficiency are fronted, in addition to the landscape approach in packaging the interventions. The impacts of such intervention even stretch to achieving the land degradation neutrality concept which is promoted to achieve stable and quality landscapes in space and with time. The adoption of combined approaches (physical, biological, agronomic and nutrient management packages) avail more water and nutrients although these can be laborious, time consuming, costly and demanding in skills. These biophysical benefits supersede the economic benefits since these integrated measures control soil loss, reduce run-off and minimize evaporation; replenish nutrients, and optimize production of food, forage, fuel and income (Martínez-Mena et al. 2020). Soil and water conservation measures such as physical structures, often result in long-term benefits (not immediate returns) compared to crop improvement technologies such as nutrient application. In order to overcome such limitations, it is advisable that emphasis in land management be on immediate intervention (moisture conservation and soil fertility) while the physical structures are simultaneously established (Ellis-Jones et al. 2001). This approach is highly commendable especially among smallholder farmers who cannot afford the complete combined package.

Use of a combination of technologies can be a success when other social-cultural factors are considered. It is critical to establish the landscape environment, the farmers' conditions in terms of their aspirations, effectiveness, preference and capacities but also understand the various needs that influence capacity to use some technologies (Emerton and Snyder 2018). Most smallholder farming communities are habitually stationed in sloping landscapes (steep, moderate and gentle slopes) in the region with varying needs for SLM interventions. It is important to observe the characteristic nature of farmers and farmlands while promoting SLM principles. The governance systems at catchment/landscape level ought to be considered since most SLM practices are not effective at farm level alone but at landscape (catchment) level. An economic analysis of the implications of using combined technologies is vital in adoption. The computation of net returns on costing the interventions can guide on possible investment options to restore degraded land. Physical structural measures remain costly for most poor smallholder farmers (Ellis-Jones et al. 2001). Recent findings indicate that there is need for simple practices for SLM with support of policy since costly practices take longer for higher returns to be realized (Dallimer et al. 2018). Technologies that require less resources (e.g., intercropping, mixed cropping, manure etc.) might be more dependable with less implementation costs compared to constructed soil conservation measures (e.g. physical terraces, trenches etc.) though the need might be guided by the setting in the landscape ecology. Some of these measures require collective action at catchment level. In all, combined packages of water and nutrient management are envisaged to have a higher cost-benefit ratio both in the short run (short-term establishment phase) but also in the long run (long-term maintenance phase). Therefore, a combination of technologies remains the most dependable and impactful management approach to avert the challenges of low productivity, soil loss and nutrient depletion. However, on-site evaluation with people-centered choice of options for application would promote sustainable land management and transform livelihoods. Research to explore various practices and technologies is vital since there are limited studies on the efficiency of various SLM measures in the great lakes region.

8 Conclusion

Nutrient application and soil water conservation are critical measures in achieving sustainable land management. The application of integrated approach for optimizing soil fertility and moisture is the most promising since it is effective and impactful. However, the success of nutrient and soil water management measures require the involvement of stakeholders especially the lead land users who are the farmers. Additionally, the computation of the cost effectiveness in the use of integrated technologies is a major incentive and a lead driver for adoption. However, the most affordable technologies can be implemented with the farmers' full consent in terms of technology acceptability and viability both in the short and long-run. Deciphering farmers' perceptions and choice in decisions for adoption of any SLM practice is important. The decisions may vary from farm unit level to village or landscape level if SLM is to provide higher societal and environmental benefits. Innovations from evidence-based research processes in the communities combined with capacity building in integrated technologies, policy and all social economic pillars of SLM are fundamental in stimulating land and water productivity.

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