Celebrating 10 years

Journal of Environmental Monitoring

Cutting-Edge Research on Environmental Processes & Impacts

www.rsc.org/jem

Volume 10 | Number 5 | May 2008 | Pages 577–684

ISSN 1464-0325

RSC Publishing

10th Anniversary Review
Richard Thomas
Sustainable land management

Hot Article
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TEQs for baseline toxicity

1464-0325(2008)10:5;1-8

10th Anniversary Review: Addressing land degradation and climate change in dryland agroecosystems through sustainable land management

Richard James Thomas*

Received 29th January 2008, Accepted 31st March 2008
First published as an Advance Article on the web 10th April 2008
DOI: 10.1039/b801649f

Sustainable land management (SLM) is proposed as a unifying theme for current global efforts on combating desertification, climate change and loss of biodiversity in drylands. A focus on SLM will achieve the multiple goals of the three UN Conventions (UNCCD, UNFCCC and UNCBD) and in particular will address the roots causes of poverty and vulnerability to climate change rather than a current focus on adapting to climate change. The interlinkages between land degradation, climate change and loss of biodiversity are outlined together with a proposed set of interventions to achieve multiple goals. It is argued that improved land productivity is a viable goal to reduce poverty in drylands provided it is linked to payments for environmental services and better crop and weather insurances and coupled with alternative livelihoods that are not primarily dependent on land productivity. Obstacles to the achievement of SLM are discussed and the steps necessary to overcome them are presented. It is suggested that promoting SLM would be a better focus for the UNCCD than combating desertification.

Introduction

The true measure of agriculture is not the sophistication of its equipment, the size of its income, or the statistics of its productivity, but the good health of the land, The Unsettling of America, W. Berry.[1]

International Centre for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria and Visiting Professor, Arid Land Research Center, Tottori University, 1390 Hamasaka, Tottori, 680-0001, Japan. E-mail: r.thomas@alrc.tottori-u-ac.jp; Fax: +81-857-29-6199; Tel: +81-857-21-7272

Richard Thomas holds a BSc in Botany and Microbiology and a PhD in microbial physiology from the University College of Wales, Swansea. He has undertaken research in plant physiology at the Universities of Bern, Switzerland, Madison-Wisconsin, USA and Dept. of Biological Sciences, Dundee, Scotland before serving 6 years at the former Hill Farming Research Organization, Penicuik, Edinburgh (later the Macaulay Land Use Research Institute). He joined the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia in 1989 before moving to the International Centre for Agricultural Research in Dry Areas (ICARDA) in 2001. He is currently a Visiting Professor at the Arid Land Research Centre, Tottori University, Japan. His research interests are in integrated natural resources management, combating land degradation and climate change in drylands.

These words express what has now become a global concern for the state of our agricultural land and the surrounding environments. Increased agricultural productivity has been successfully achieved to avoid the earlier predictions of global famines but it has come with a price tag of land degradation from inappropriate and unsustainable practices.

This is nowhere more evident than in the world's drylands that occupy around 41% of the Earth's land area and house as much as one third of the world's population. These lands are subject to desertification or land degradation but estimates of the actual amounts affected are not known precisely and vary widely from 10 to 70% degraded.[2] As most of the world's rural poor inhabit drylands, with perhaps as many as 1 billion dependent on dryland natural resources (land, water and plant and animal biodiversity) for goods and services,[3] there is concern over the state of the resource base and the future well-being and livelihoods of dryland inhabitants.

This concern is now compounded by the predictions that drylands will become hotter and drier with more erratic rainfalls with climate change thus increasing the vulnerability of the rural poor to environmental and socio-economic stresses.[4] Drylands are considered to be the most vulnerable terrestrial ecosystems to climate change.

With the increasing urgency to act, there is a need to be more proactive rather than reactive and to focus first on measures that achieve multiple goals, *i.e.*, that address not only the impacts of land degradation but also other stresses such as climate change and loss of biodiversity. The United Nations Convention to Combat Desertification (UNCCD) has argued that integrated projects for the rehabilitation of degraded land are required that link efforts on land degradation, climate change and loss of biodiversity.[5] This article argues that a focus on sustainable land management can contribute to these multiple goals.

Sustainable land management (SLM) has been defined as "management that combines technologies, policies and activities

aimed at integrating socio-economic principles with environmental concerns so as to simultaneously:

- maintain or enhance production/services (Productivity)
- reduce the level of production risk (Security)
- protect the potential of natural resources and prevent degradation of soil and water quality (Protection)
- be economically viable (Viability)
- and socially acceptable (Acceptability).[6]

An alternative definition describes SLM as a knowledge-based procedure that helps integrate land, water, biodiversity and environmental management to meet rising food and fiber demands while sustaining ecosystem services and livelihoods.[7]

The achievement of SLM requires the maintenance of a protective biological surface cover (living plants or mulches), good soil structure to allow gas, water and nutrient exchanges between soils and plants and adequate levels of soil organic matter and their soil-inhabiting organisms.[8] These measures would also reduce the greenhouse gas (GHG) emissions associated with food production. Others opine that SLM requires a focus on the soil, vegetation and primary productivity.[2]

The achievement of SLM requires not only a consideration of the biophysical driving forces but also the socio-ecological factors that determine how land is used. These factors include livelihoods and markets for products and the asset base of the land users in terms of physical, human, social, financial and natural capitals.[9]

Farmers' perspectives of SLM are often different from researchers, development agencies and policy makers.[10] Their indicators of sustainability differ also. For example, farmers may view crop diversification, access to inputs, enough farmland to feed their family, especially during dry seasons, having affordable equipment and tools and use of crop rotations to maintain soil fertility as indicators of sustainable agriculture rather than declining productivity, soil loss or deteriorating water quality. For many poor farmers, land degradation is either not perceived as costly or not important, especially if there are no clear land tenure or property rights agreements that encourage farmers to invest in natural resource conservation. Generally, it is essential that any attempt at introducing SLM practices should result in improved income generation for the land user within one growing season. A corollary to this is that the introduction of income generating activities must also be linked to SLM or there is a risk of further land degradation from over exploitation of the resource base.

Land degradation is the opposite of SLM and is defined by the UNCCD as 'a reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands, including processes arising from human activities and habitation patterns. These include; (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation'.[11] A simplified definition is a persistent decline in the ability of a dryland ecosystem to provide goods and services associated with primary production.[12]

Efforts to combat desertification or land degradation in drylands necessarily focus on sustainable land management. Land degradation is the specific topic of the UNCCD but in fact it is increasingly recognized that efforts to achieve SLM bring benefits to the other conventions on climate change, the United Nations Framework Convention for Climate Change (UNFCCC) and the United Nations Convention on Biological Diversity (UNCBD).

There remains much debate on the global extent of land degradation in drylands with claims of between 10 and 70% of the total dryland area degraded.[2] The Millennium Ecosystem Assessment, which is the most recent attempt to quantify land degradation, favours a medium certainty figure of 10–20%.[13]

With advanced technological developments centering around remote sensing and geographic information systems for land surveillance and our increasing ability to link biophysical data with socio-economic data, we can expect increasing accuracy in the estimates of the extent and costs of land degradation and causal factors in the near future from a number of on-going projects and programmes.[14]

Whereas there has been controversy over the causes of land degradation, a greater appreciation of the complexities and the need to take account of the socio-ecological perspectives has resulted in better analytical and conceptual frameworks that help distinguish between the numerous factors that can result in degradation.[15–19] However, while these frameworks emphasize a systems approach and distinguish different typologies of land degradation that help explain direct and indirect causes, they have yet to result in practical guidelines for remedial treatments. Further diagnostic efforts will help to develop and better target solutions or remedial actions for specific contexts and different scales. Important in this context is the realization that land degradation is often driven by slow variables, such as loss of soil organic matter, that are not easily perceived. Most causes of land degradation involve regionally distinct mixtures of socio-economic and biophysical factors that may act directly or indirectly, rather than single factors.[15]

Interlinkages between land degradation, biodiversity and climate change

Land degradation directly affects biodiversity and interacts with climate change *via* the loss of above- and below-ground flora and fauna as a result of habitat change and by altering carbon and other GHG fluxes and cycling. These interlinkages are illustrated in Fig. 1.[13]

Any change in climate that increases the frequency of severe episodic events such as heavy rainstorms will clearly affect land degradation *via* increased soil erosion. This will be particularly important where annual rainfall lies between 500–750mm, a range where violent storms are possible but where there is likely to be insufficient ground cover.[20] Similarly, the loss of soil will limit ground cover and thereby affect the surface albedo and associated effects on surface evapotranspiration and heat and moisture fluxes that will in turn affect local, regional and possibly global, atmospheric circulations.[21] Lower plant productivity will affect carbon fluxes, will lower carbon reserves in vegetation and soils and will increase GHG emissions.

Land degradation results in the loss of soil and plant biodiversity because of the loss of soil organic matter and nutrients and C energy inputs that drive many biological soil processes. This results in lower land productivity, together with

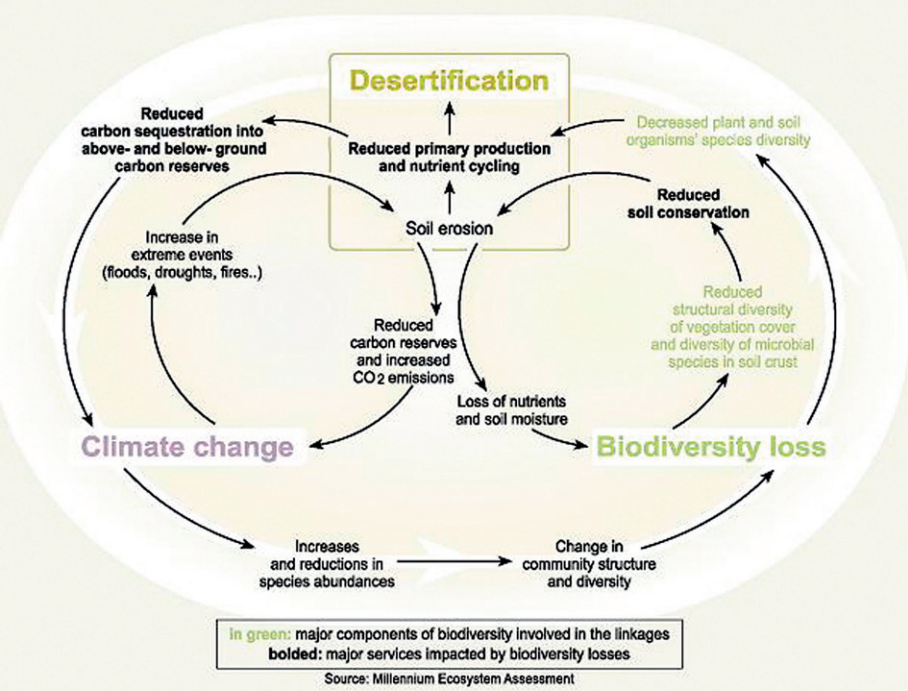

Fig. 1 Interlinkages between desertification, climate change and biodiversity as described by the Millennium Ecosystem Assessment.[13]

the loss of habitats for key functional groups of species (*i.e.*, sets of species that have similar effects on a specific ecosystem-level biogeochemical process).[22] Changes in land use, such as deforestation and conversion into grasslands, are often associated with land degradation, and inevitably alter biodiversity.

Climate change is expected to decrease the number of habitats as temperatures warm although the specific impacts are too complex to predict accurately. However, movements of plants and animals and their associated pests and diseases beyond their natural limits have already been reported.

Why a focus on SLM will address these interlinkages

It is clear from the above discussion that at the biophysical level, maintaining a cover over the ground and developing a better stewardship of the flora and fauna will help prevent and reverse land degradation, increase the resilience of ecosystems to climatic and human-induced stresses and thereby contribute to the conservation of biodiversity and mitigation of climate change. For other global concerns SLM will increase productivity and income thereby helping to achieve the Millennium Development Goal number 1–to eradicate extreme poverty and hunger, and number 7, –to ensure environmental sustainability.[23]

There are many options where efforts to achieve SLM have spill over effects on improving the resilience of the agro-ecosystems, and mitigation and adaptation to climate change. Some examples of these are given in Table 1. Details of these technological interventions are well known and are reported extensively elsewhere.[7,24–27] These include switching to conservation agricultural practices such as no- or minimum tillage to enhance soil organic matter and biota, crop rotations with a legume component as a source of biologically fixed nitrogen, and water conservation through water harvesting and supplemental irrigation.

Recuperating degraded drylands can result in the sequestering of 12–20 Pg C over a 50 year period if the SLM practices outlined in Table 1 are successfully applied.[25] This represents about 1 Pg C yr^{-1} or around 30% of global annual increase in CO_2 concentrations. These estimates are admittedly crude but highlight the magnitude of the potential benefits that can be achieved globally through a focus on SLM.

Can SLM be achieved in drylands?

It is usual to depict drylands as zones of perennial misery, starvation, conflict and hopelessness. There are links between land degradation in drylands and increasing civil and armed conflicts. However, while these stories make compelling headlines, they mask progress that has been made. Recent studies showing greater returns to development investments in drylands than elsewhere belie the image of hopelessness.[28]

Examples of bright spots where progress has been made in reversing land degradation include reforestation of degraded lands and improved soil and water conservation drawing on local knowledge.[29–31]

Nevertheless, real and daunting challenges remain, such as persistent poverty, recurrent droughts, impending climate change, globalization, and degradation of the fragile resource base. In addition, there is an apparent reluctance of farmers to adopt new SLM technologies.

According to the recent World Development Report,[32] most dryland countries can be classified as either agricultural-based or are transforming countries with a third category called urbanized countries that have few dryland countries. Using this classification it is suggested that there are four pathways out of poverty;

Table 1 The role of SLM options in contributing to ecosystem resilience and prevention of land degradation, mitigation and/or adaptation to climate change in drylands

Sustainable land management options	Improvement of ecosystem resilience and prevention of land degradation	Mitigation of climate change	Adaptation to climate change
Technical interventions			
Conservation, characterization and sustainable use of genetic diversity and plant improvement for tolerance to abiotic stresses (extreme temperatures, droughts, flooding, salinity)	Understanding of functional biodiversity and 'keystone' species will help maintain ecosystem functions and resilience	Increased C sequestration, reduced GHG emissions from farms and natural habitats In situ conservation of adapted biodiversity	Better targeting of germplasm to specific environments
Collection and use of commercially promising and/or underutilized plants with high value and lower water use	More efficient water use		Introduction of new commercial species with low water requirements, to increase livelihood options
Development of biological controls of pests and diseases under changing climates and plant improvement for biotic stresses	Less reliance on pesticides and herbicides	IPM options will reduce vulnerability to changes in pathogen distribution	Better control, improved prediction of pest and disease infestations
Better management of livestock, pastures and rangelands	Less overgrazing, more sustainable pastures	Increased C sequestration in rangeland soils and biomass	Increased drought preparedness
Diversification of livelihoods, including new crop-tree-livestock options	More sustainable production systems, increased biodiversity	Increased C sequestration, reduced GHG emissions	Wider range of production system options for climate variability
Conservation agriculture, including minimum and no-tillage and crop rotations with food and cover crop legumes	More robust cropping systems will conserve natural resource base *via* increased ground cover	Increased C sequestration, lower energy requirements	Wider range of production system options for climate variability
Improved water-use efficiency, water allocation	Conservation of water resources will help maintain environmental services	Reduction of GHG emissions from soils	Production systems adapted to climate variability, especially water scarcity
Improved management of marginal-quality water (treated wastewater, saline water)	More sustainable water use, maintenance of environmental services	Increased biomass production and C sequestration	Production systems sustained despite of the use of marginal-quality water
Improved soil management and soil fertility, combining and balancing all nutrient resources	Increased soil organic matter will increase water holding capacity and nutrient cycling	Increased soil C sequestration	Higher soil organic matter will reduce risk of crop failure from floods, drought
Amelioration and management of salt-affected soils	Salinity mitigation will increase productivity and ecosystem health	Increased soil C sequestration	With improved crop productivity, amelioration will slow down loss of arable land; in certain cases amelioration will bring back the degraded soils to a highly productive state
Policy and institutional interventions			
Development of better policy and socio-economic environment for of co-management of water resources	Greater investment in protecting environmental services	Enabling environment for more sustainable production practices	Enabling environment for more sustainable production practices and enhanced uptake and impacts of improved technologies
Documenting and understanding the benefits and trade-offs between development, climate change and land degradation	Improved ecosystem management		Improved ecosystem management for long term sustainability

through smallholder farming, wage employment in agriculture, employment in rural non-farm economy or migration out of rural areas. For agricultural-based countries the first priority is to increase agricultural productivity, while for transforming countries the suggested priority is to decrease the rural-urban income gap and focus on all pathways out of poverty but especially by increasing high value products. Emphasis is given in all scenarios to a need to ensure that productivity increases per unit of land, water or increased income per unit area should not occur at the expense of the degradation of the natural resource base.

Of importance for these scenarios is the idea of focusing on alternative livelihoods for drylands. Fig. 2 shows a proposed strategy for achieving sustainability in drylands by considering two major pathways (adapted from Adeel and Safriel).[33] The first, on the left-hand side of the figure, can be termed sustainable or integrated land management. It focuses on improving land and water productivity by introducing measures such as those outlined in Table 1.

This pathway continues to hold promise as there remain large yield gaps in drylands (*i.e.*, the gap between yields obtained under best conditions, usually on research stations or demonstration farms, and those obtained in farmers' fields). For example, for Ethiopia, Nigeria, Mali and Mozambique, that are mainly dryland countries, it has been estimated that the gap is between 2- and 5-fold.[32] These gaps can be addressed by increasing the

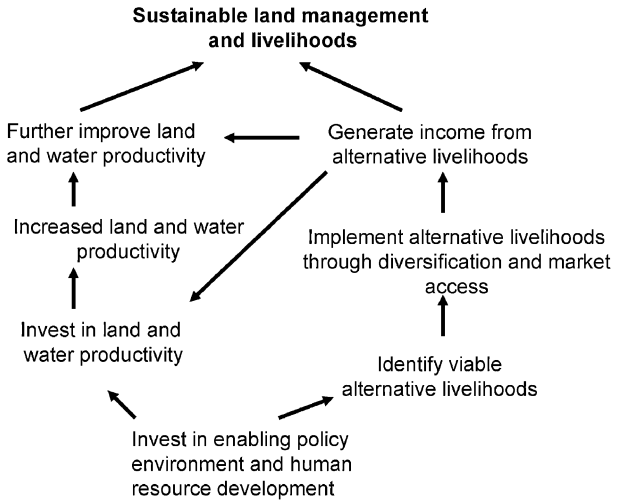

Fig. 2 Pathways for attaining sustainable land management in drylands through consideration of agricultural and alternative livelihoods (adapted from Adeel and Safriel).[33]

efficiency of water and nutrient management practices, increasing the efficiency of the supply of water from its current low value in drylands, introducing integrated pest management and adapted plant and animal germplasm. Much can be achieved by re-working our research hypotheses and questions. For example, rather than determining how much fertilizer needs to be applied to maximize crop yield, farmers need to know how much fertilizer he/she can afford and when and how is it best applied to which crop for food security and income generation.

Substantial increases in crop yields and water use efficiency/water productivity are possible in all agroecosystems of the dry areas. Passioura[34] has emphasized that in terms of water productivity, greatest gains for crop production can be made by ensuring that more available water is transpired by plants at critical times of crop development and that losses *via* soil evaporation and weeds, drainage and run off are minimized. This includes the need for a rapid establishment of ground cover and minimum tillage to reduce soil evaporative losses and ensuring adequate water supplies after anthesis. These are essentially agronomic practices that are already known but that are not widely applied in farmers' fields. Supplemental irrigation in rainfed areas, for example, increases water productivity 2 to 4 times that of rainwater or full irrigation. Water harvesting, first used over 2000 years ago in drylands,[35] can save 40–50% of the runoff in rangelands that is otherwise lost to evaporation or salt sinks. This remains a viable option where there is land to 'sacrifice' for water. Deficit irrigation combined with appropriate cropping patterns in irrigated areas can double economic water productivity.[36] It has been shown that farmers in drylands are over-irrigating their crops by as much has 20–60%[37] and therefore practical means to advise farmers when not to irrigate need to be further developed and disseminated.[38] Irrigation at 80% full irrigation has saved 250 m^3 water ha^{-1} on pilot farms in Pakistan and although yields were highest under full irrigation, economic returns on the crop plus the saved water were highest at 60% full irrigation (ICARDA unpublished).

Improvements in plant genetics *via* molecular and other biotechnological tools to enhance conventional plant breeding for the development of shorter duration crops and more rapid leaf development under environmental stresses (heat, cold, salt and pests and diseases) will complement improvements in agronomic practices.[34]

New possibilities of gene mining, as well as *in situ* germplasm conservation, are vital to these efforts geared to meeting the challenge of climate change.

Integrated crop-livestock systems and pastoralism predominate in drylands with around 70% of the drylands in developing countries devoted to rangelands.[12] Livestock not only make important contributions to economies but also provide fuel through manure, recycle nutrients and are used for transport and draught. Livestock are often the main capital resource of poor households. Livestock performance can be considerably improved by focusing on alternative feed resources, especially during periods when native vegetation or forage is scarce and through technologies to improve reproduction.

Also key is the need to express productivity not just in terms of output per unit area but in terms of output per unit water and income per unit area (bioeconomic capacity) in order to take account of the need for higher value products that use less water and that are less extractive of other natural resources than the predominating crop-livestock systems.

In addition to the technical factors responsible for the yield gap there are other socio-economic and institutional factors that limit productivity. One of the most important is the lack of land tenure and property rights and the well known reluctance of farmers to invest in land improvement when they do not own or control the land.[32]

From the few examples above it is evident that even though drylands have inherently lower productive potential than other ecosystems,[39]the limit of productivity of the dryland ecosystem has not yet been reached and there is much scope for improvements *via* greater efforts in research and development and dissemination of information. This research needs to be combined with a co-management approach to natural resources where local communities have increasing responsibility for the management of the resources available to them.[40,41] A more conducive policy and institutional environment is required to help facilitate these developments.[41] Thus it is argued that most drylands are still below the threshold point where sustainability turns into desertification.[39]

In addition, through integrative approaches it is now possible to better target technical interventions to those sectors of society who can benefit most from them. A study of various options in North-western Syria for example, indicated that the most promising interventions such as lamb fattening, improved barley varieties, olives and cumin as a new cash crop, would only directly benefit those who are already better endowed in livelihood assets such as capital.[42] Such studies are important in order to disentangle the heterogeneity of dryland livelihoods so that more appropriate interventions can be developed for different household typologies.[32]

As seen from Table 1, technical options are available for improved land productivity but are not enough to achieve SLM and it was argued in a visionary publication by Méndez,[43] that there is a need to introduce alternative livelihoods into dryland communities that have minimal dependence (and pressure) on land resources. Indeed, there is further evidence that where there

is a lack of alternative livelihoods the degradation–poverty linkages are exacerbated.[44] This pathway is shown in the right-hand side of Fig. 2. Examples of alternative livelihoods include adding value to existing plant and animal products by processing, apiculture, aquaculture using low quality water, controlled-environment agriculture under plastic-covered housing for high value products, renewable energy generation (solar and wind, rather than biofuels which rely on primary land productivity) and ecotourism. A futuristic scenario for energy generation, for example, includes the establishment of a European–Middle East–North African network of concentrated solar thermal power plants over an area of 2500 km^2 of desert land that will generate electricity and desalinize water.[45] An interesting possibility is that such water, although not sufficient for agriculture, could be used for irrigating covered housing plant production facilities or used for aquaculture that would be capable of absorbing both labour and capital investments in drylands.

For both pathways, research on technical aspects is of limited use if there is weak environmental governance and no land tenure or property rights that can be major bottlenecks to progress. Both pathways can also result in adverse affects on land degradation through international trade and an over emphasis on production for export, further marginalization of small holders, and inappropriate or perverse government policies and macroeconomic reforms. Both pathways need careful analyses to ensure the focus on sustainability and protection of the natural resource base is not lost.[46] Both pathways also require considerable investment in human resource development (Fig. 2) as the educational levels of the rural poor remain woefully inadequate, especially in dryland countries with figures of less than 4 years education for adult males.[32,47]

Further bottlenecks include creating a better enabling environment for investment and infrastructure that can better link producers to markets (Fig. 2). Of additional importance and requiring further research, is the destination of resources generated by alternative livelihoods. Studies are required to determine how dryland inhabitants can re-invest their incomes from this alternative livelihood pathway and what policies and incentives are required to invest more in land productivity up to the theoretical threshold point between sustainability and desertification. As pointed out by Adeel and Safriel[33] the development of both pathways simultaneously plus the interacting flow of resources between them (mainly income) can act as powerful buffers to economic shocks, land degradation and climate change.

Another obstacle to the implementation of SLM technologies and practices is the apparent reluctance of farmers to adopt new interventions when 'supplied' from external agencies. These include the noted lack of perception of land degradation as a serious or costly problem by farmers, especially when it manifests itself only over long term periods, *e.g.*, a gradual decline in soil organic matter or eroding hill lands that are non-productive from the farmers' perspective.[48] Other factors include a reluctance to invest in new unfamiliar equipment and any change in farming operations, a lack of perceived short-term pay offs, risk aversion with untried practices as well as previously mentioned tenure and property rights weaknesses. These are some of the reasons why building on existing practices and customs clearly has advantages over new unfamiliar ones.[49,50]

It is important to reiterate here that the returns on investments in dry areas (less favoured areas) are now higher than those in more favoured areas (irrigated, close to markets).

The high threat to food security of dryland countries should ensure that there is increased investment of both public and private funds into agricultural research and development. This is reinforced by the recent data that agriculture remains a key driver of poverty reduction even in areas where the majority of income is not derived from agriculture.[32] Along with greater investments in research for development is the need to establish agricultural risk management strategies for the resource poor through developments such as crop and weather risk insurances and newer index insurance alternatives.[51] These types of insurances are needed to overcome the risk aversion strategies favored by poor farmers that forego higher incomes that could be achieved through investing in SLM practices.

A further impetus to investment in SLM in drylands could be the increasing interest in payments for environmental services or PES.[52–55] This concept recognizes that agriculture is the largest managed ecosystem and is expected to help maintain key environmental services such as nutrient cycling, water purification and supply regulation, pollution filtration, pollination and seed dispersal, maintenance of soil organic matter, carbon sequestration, biodiversity and provision of food, fiber and forage.[56] Currently, farmers are not encouraged or paid to take particular care of these services especially when they extend beyond the farm boundaries. However, because farming impacts are also external to the farm there is increasing interest in directly paying farmers to preserve and enhance the delivery of ecosystem services from the land. To date these have focused mainly on mitigating climate change through carbon sequestration particularly in forests, enhancing water quality and conserving biodiversity. PES is based on the principle that providers of environmental services should be compensated for their costs and that the beneficiaries should pay for them.[55]

For drylands the main challenge in terms of addressing land degradation through PES is how to develop viable schemes for the preservation and rehabilitation of rangelands that occupy the majority of the land area.[52,53] With rangelands there are particular difficulties over ownership, common access and use, who are the beneficiaries and who benefits from the environmental services they provide. It is also likely that because primary productivity in drylands is lower than for other ecosystems, schemes such as afforestation need to be combined or 'bundled'[57] with other ecosystem services such as wind erosion reduction, conservation of biodiversity and improved water productivity and flood control.[52] New programs are being developed to use compensation for environmental services as incentives for SLM in drylands.[54]

New methods to monitor changes in environmental services are required that need to be selected by the communities who will co-manage the natural resources. These will need to be cheap, easy to understand and use and will evolve from a hybrid knowledge system that combines local and scientific knowledge.[58,59]

Interesting questions evolve around issues concerning the trade offs amongst maximizing environmental services while improving crop/livestock production and managing risk at the farm and household level to achieve SLM and viable livelihoods.

Models are being developed that help policy makers and farmers decide on issues such as the implementation of a land use management practice that provides food, fiber or fuel compared with one that gives greater emphasis on water supply or carbon sequestration.[60,61]

Dealing with the complexity of rural development and integrated natural resource management (INRM) is a daunting challenge that involves breaking down institutional and departmental barriers between research and development agents and decision makers.

However, tools for INRM are being developed including participation in watershed and common property functions especially water management, and approaches that ensure quick returns to farmers from investments in SLM practices.[41,62,63] Lessons learned from these experiences suggests that a change in the management of ecosystems requires careful attention to building knowledge and networking and ensuring strong leadership roles that span bridges across levels of governance, policies and institutional perspectives.[64] The combination of scientific and local monitoring methods has been shown to help strengthen participation, build partnerships and the required common vision and understanding.[65] Rather than advocate for bottom-up approaches and changes this literature also suggests that it is the combination of bottom-up and top-down approaches that is required to handle the various scales (physical and institutional) and that informal or 'boundary' organizations, made up of relevant stakeholders, improve information flows, identify knowledge gaps, are more free to suggest alternative options and scenarios and create groupings or nodes of particular expertise needed for ecosystem management.[66] A recent example of such boundary organizations is available from ICARDA's work in the marginal drylands of Northern Syria[67]

Campbell *et al.*,[41,68] provide a practical guideline to achieving INRM based on three sets of principles concerning, (i) learning approaches, (ii) systems approaches, and (iii) organizational models that are sub-divided into 11 operational guidelines. These authors suggest that the framework to which the 11 guidelines are attached can serve as an analytical tool to help; determine the main driving forces behind land degradation and other NRM problems, develop strategies, planning, monitoring and evaluation of land degradation initiatives. In addition the framework facilitates gap analysis, identifies critical intervention points and priorities and can be used for knowledge management to facilitate the feedback of lessons and experiences during the process.

The need to mainstream land degradation and adaptation to climate change into development policy

Under the UNCCD, the instruments to help mainstream land degradation into development are primarily the National Action Programmes (NAPs) with emphasis on the involvement of civil society. The UNFCCC has its equivalent National Action Programmes for Adaptation (NAPA) that have more focused short-term goals but less implementation experience. The NAPs however have had very limited success in attracting attention of policy makers and in their implementation. Refocusing these programmes on SLM will achieve the objectives of uniting efforts to tackle the objectives of the three UN Conventions and will sharpen their focus. UNCCD should take the lead in this area as it is the only international binding agreement for sustainable land use that attempts to link poverty reduction and environmental protection.

Much effort is currently being made to introduce adaptation strategies for climate change into development based on the recognition that some climate change is inevitable and there is a need to help the most vulnerable communities (the rural poor) adapt or cope with the expected deleterious effects of climate change.[69] Climate change will mostly affect the natural resource base (soil, water and vegetation) that the rural poor in drylands depend on for their livelihoods. However, a focus on adaptation, while worthy, does not address the root causes of the vulnerability of the poor to climate change and other stresses and it has been argued that without such an effort, measures to adapt to climate change will not contribute greatly to development.[70] Rather, a focus on SLM will help address root causes of low productivity, land degradation, loss of income generating capacity as well as contribute to the amelioration of the adverse effects of climate change.

Building on other evidence,[71,72] the bottlenecks to mainstreaming that need to be overcome include;

1. Lack of awareness of the seriousness and links between land degradation and climate change within the development community.

2. In the case of land degradation the UNCCD suffers from a lack of focus on the main issues to be addressed within the complex of both poverty reduction and environmental protection.

3. Many projects have too limited a time frame of 3–5 years when the response will be required over the long-term, in spite of the fact that quick results are essential to encourage land user participation and commitment.

4. The convergence of many issues all trying to be integrated into development activities may be creating 'mainstreaming overload' *i.e.*, desertification, climate change, human diseases, gender, education, and population growth.

5. Barriers within governments and donor agencies, *e.g.*, expertise in land degradation and climate change are frequently only in agricultural or environment departments that have limited leverage over sectoral guidelines and policies.

6. Insufficient relevance and accuracy of available land degradation and climate information to development-related decisions. This includes the well recognized gap in knowledge between the global climate circulation models and regional/local needs and the uncertainty over the extent and costs of land degradation.

7. Limitations on resources for implementation.

Conclusions

That SLM is a necessary goal to alleviate poverty and protect the environment in drylands is well recognized. However, efforts to achieve this aim have been fragmented and dispersed both amongst the United Nations environmental conventions and within the scientific research for development community. Cross disciplinary research to tackle the complexities of managing socio-ecological systems for multiple goals is still relatively rare and poses severe challenges for the way research is organized.

This paper attempts to establish the basis of a framework where coordinated efforts on SLM can be established by indicating the broad-based approach needed and how multiple goals of preventing or reversing land degradation, adapting to climate change, and reducing biodiversity loss can be achieved while improving livelihoods.

To achieve a SLM that addresses both land degradation and the impacts of climate change with the added benefit of helping avert loss of biodiversity, the following steps are required;

1. An assessment of the current land conditions and where possible the change of conditions over time using remote sensing and ground truthing.

2. An assessment and further understanding of the interplay of climatic and socio-economic factors that result in loss of productivity and land degradation.

3. Risk assessments of climate variability and long-term changes using seasonal and longer-term forecasting linked to agricultural activities and insurance schemes for the rural poor.

4. Addressing the bottlenecks to mainstreaming linked efforts on land degradation and adaptation to climate change into development processes (legal and policy frameworks and incentives).

5. Development of low cost monitoring, evaluation and modeling tools for land degradation and environmental services that can be used by land users and policy makers for decision making and for compliance purposes such as soil organic matter, carbon sequestration and water quality.

6. Dissemination and capacity development on climate risk and land degradation bringing together land users with dispersed agencies such as the national meteorological, hydrological and agricultural services.

Despite the enormous challenges to achieve SLM, many of the technologies are already available and there is now greater understanding of the constraints behind the lack of adoption of these technologies. These have often been bottlenecks in the institutional and policy environment. With the change in perspectives of the role of agriculture in development, and the rapidly developing interest in payments for environmental services, the developments in crop and weather insurance schemes and the recognition that decentralised approaches to natural resource management are more successful than centralized approaches, there is now greater optimism that dryland populations can achieve SLM and viable livelihoods.

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