Chapter 22
A Risk-Based Strategy for Climate Change Adaptation in Dryland Systems Based on an Understanding of Potential Production, Soil Resistance and Resilience, and Social Stability

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Attention must be given to ensuring high productivity from stable soils, restoring and sustaining the productivity of resilient soils, and conserving fragile and marginal soils.

(Greenland et al. 1994)

Abstract Climate change is expected to increase the intensity and temporal variability of storm events in many areas while reducing their frequency, resulting in increased runoff, and drought frequency and severity. Soil degradation can exacerbate these impacts by reducing both infiltration and plant-available water holding capacity. Therefore, an understanding of soil resistance and resilience to degradation is necessary to target climate change adaptation investments where they will have the largest impact. This paper (1) reviews key concepts necessary to understand the dynamic relationships between climate change adaptation, soil resistance and resilience, and social stability, and (2) provides a strategy for maximizing return on climate change adaptation investments in drylands based on an understanding of soil and ecosystem resilience. The strategy includes seven steps, which are completed for each landscape unit in the context of the surrounding landscape: (1) Determine current potential productivity based on soils, topography, and existing climate conditions. (2) Determine future potential productivity based on soil, topography, and climate change scenarios. (3) Rank landscape units based on predicted change in potential productivity. (4) Determine risk of land use change. (5) Determine degradation risk with and without land use change. (6) Rank each landscape unit based on

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degradation risk with and without land use change. (7) Determine priorities for climate change and soil conservation investments. The strategy described here can be applied on multiple scales to address a wide variety of objectives. We conclude by suggesting that climate change adaptation resources allocation decisions include consideration of soil resistance and resilience.

Keywords Soil degradation • Social stability • Soil resistance and resilience • Discount rates • Livelihood security • Livestock migration • Conflict and soil degradation

22.1 Introduction

Global population and per-capita food consumption are expected to continue to increase through at least 2050, with caloric intake increasing to over 3,100 kcal per day (Kearney 2010). Climate change is expected to negatively affect food security in many regions while soil degradation has already dramatically reduced food production and other ecosystem services (Lal 2001). Soil erosion is estimated to result in a US$ 640 million annual loss to society, exceeding losses due to deforestation, over-fishing, and overuse of water resources (UNEP 2012). Research efforts dedicated to land degradation, however, lag significantly behind those allocated to climate change: the phrase “climate change” was used in more than 80,000 articles published in 2012, while only ~10,000 publications referred to “land degradation” or “soil degradation” (Herrick et al. 2013a). Research on soils and climate change has focused on mitigation, although improvement in soil quality is often cited as a co-benefit of carbon sequestration (Lal 2004) rather than adaptation. In this chapter, we argue that an understanding of soil resistance and resilience to degradation is necessary to target climate change adaptation investments where they will have the largest impact.

22.1.1 Climate Change and Soil Degradation

Soil degradation can exacerbate climate change impacts on food production. Climate change is expected to increase the intensity and temporal variability of storm events in many areas while reducing their frequency. Increased storm intensity further increases runoff from already degraded soils. Increased temporal variability increases the probability of extended periods with little or no precipitation, which increases the soil water storage requirements necessary to sustain plant production. At a minimum, this reduces plant production. In drylands, it can increase the frequency of crop failure. Crop failure risk is further increased by the cumulative effects of reduced water infiltration and storage in the rooting zone, together with increased evapotranspiration demand associated with higher temperatures.

In livestock production systems, which are the dominant production systems in global drylands, the impacts of soil degradation are more complex. Increased runoff

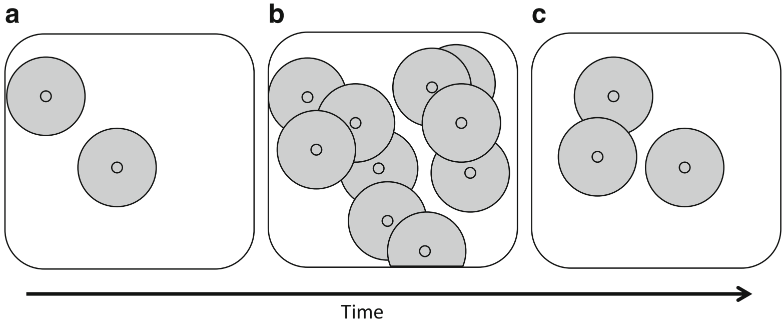

Fig. 22.1 Soil degradation increases runoff, increasing the density of ephemeral water sources (**a**–**b**), but it also increases sedimentation, reducing storage capacity (**b**–**c**)

reduces forage production, but can increase the amount of forage that can be harvested by livestock by reducing distance to water. In many semi-arid rangelands, livestock depend on ephemeral water sources. The ability of grazing animals to exploit forage resources declines with increasing distance from water (Valentine 1947). Forage utilization by cattle can be predicted by distance from water (Ariapour et al. 2013), and is generally quite low at distances more than 3.2 km (Holechek et al. 2001). Depressions that naturally collect runoff increase the accessible area by decreasing distance to water. This also reduces the energy required to move between forage and water. Ranchers and pastoralists often construct small earthen dams to increase the density of ephemeral water sources. Increased runoff can increase the amount of water captured in both natural depressions and constructed structures (Fig. 22.1). However, because runoff increases erosion, it can also increase sedimentation, reducing the storage capacity of these structures. These complex interactions between soil degradation, climate change, forage production, and forage accessibility (Fig. 22.2) have received relatively little attention from the scientific community, despite obvious impacts on pastoralist livelihoods.

Soil nutrient limitations caused by soil degradation can also exacerbate climate change–induced plant water stress by limiting plant root growth, resulting in reductions in root length density. Reductions in root length density become more important during drought because unsaturated hydraulic conductivity declines. This means that even if there are plant-available nutrients in the soil, they become less accessible to the plant during periods of high evaporative demand. This creates a positive feedback loop with negative implications for biomass production.

22.1.2 Soil Degradation and Social Stability

Dryland systems cover close to 41 % of the global land surface, and are home to close to 2.5 billion people (Millennium Ecosystem Assessment 2005). The majority of these people living in dryland systems obtain their livelihoods from the animals

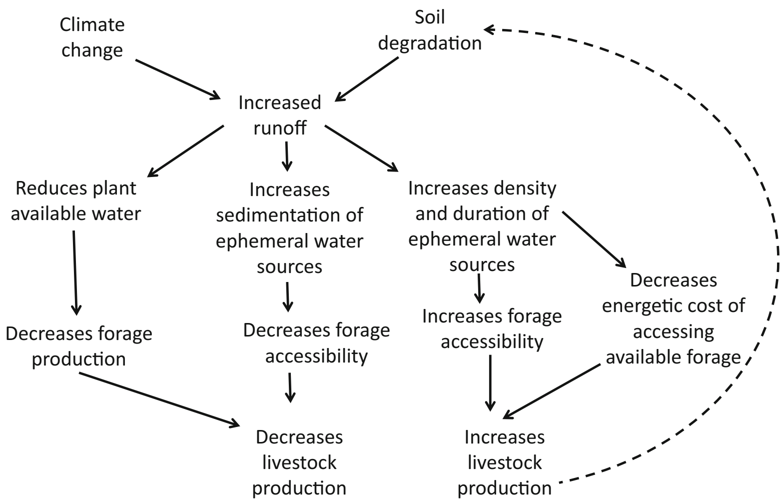

Fig. 22.2 Complex interactions and feedbacks between climate change and soil degradation

they keep and the subsequent products these animals produce. Consequently, increasing soil degradation and other negative biophysical changes due to climate change in dryland regions is as much a humanitarian concern as an ecological one. Just as soil, water, and other biotic systems are at risk of climate change–driven degradation, so too are social systems. Past studies have documented functional and structural changes in social-ecological systems in response to climate change (Cowie et al. 2011; Reynolds et al. 2007). As climate change decreases soil resistance and resilience, negative feedbacks from related changes in social systems may lead to even more soil degradation, in turn leading to increased pressures on social systems. Soil resilience and human feedback mechanisms have been empirically linked across varied landscapes in Asia (Kiernan 2010; Muscolino 2011), Europe (Prazan and Dumbrovsky 2010), South America (Alscher 2011), and Africa (Oba et al. 2010; Gray 2011). Of primary concern are soil degradation impacts and feedback loops leading to, and driven by, changes in livelihoods, security, human migration patterns, and their ultimate contribution to an increase in violent conflict (see Table 22.1).

22.1.3 Climate Change and Soil Resistance and Resilience

By definition, soils that are resistant or resilient are less susceptible to long-term degradation than those that are not. Therefore, an understanding of how soil and ecosystem resilience varies at multiple spatial scales can help land managers and

Table 22.1 Soil degradation and social stability linkages in Sub-Saharan Africa

Soil degradation—social stability linkage	Description of feedback loop
Livelihoods security	High population growth and fertility rates, coupled with poor soil quality and stagnant crop yields, result in continued reduction of carbon stock, increase erosion and sedimentation, and result in further degradation of natural resource base
	Farmers and pastoralists absorb financial loss due to crop failure, leading to an overall decrease in the rural economy
	Decrease in crop production leads to an overall decrease in household nutrition levels
	Decreased household income leads to an increased reliance on foreign food aid
	Increased dependency deteriorates existing social safety nets and contributes to reduced community resilience
Human and livestock migration	Soil degradation forces pastoralists to seek alternative pasture for livestock
	Pastoralists and farmers move in greater numbers (out-migration) to areas with better soil conditions (often in areas of marginal quality), escalating pressure on the capacity of the soil to absorb the impacts of increased grazing and farming
	As land tenure regimes trend toward private/group ownership from group ownership, access to these pastures is limited
Violent conflict	Pastoralists are forced to graze livestock on increasingly marginal lands with other tribal groups, increasing the chance of violent cattle raids
	Continued out-migration increases opportunity for violent conflict in other regions
	Compromised livelihoods, out-migration, and changing grazing patterns can weaken traditional governance mechanisms that historically have provided stability and diplomacy during times of conflict
	Continued violent conflict leads to increased soil degradation through the detritus of warfare

policymakers to design, spatially target, and prioritize investments in climate change adaptation. Maximizing food security returns on investment requires developing management strategies that sustainably maintain or increase agricultural production. Reducing the risk of long-term soil degradation must, therefore, be a key component of climate change adaptation. The objectives of this paper are to (1) review key concepts necessary to understand the dynamic relationships between climate change adaptation, soil resistance and resilience, and social stability, and (2) provide a strategy for maximizing return on climate change adaptation investments in drylands based on an understanding of soil and ecosystem resilience.

22.2 Definitions and Concepts

22.2.1 Resilience

The term “resilience” is not well-defined (Blum and Santelises 1994). Although it has been over 15 years since Lal (1997) highlighted the need to quantify soil resilience, there are still no standard methods for doing so. Nevertheless, it is a useful concept that is increasingly applied to guide policy and management. More and more, ecologists use it to refer to two distinct ecosystem properties: resistance to positive or negative change resulting from a disturbance, and potential recovery following disturbance (Scheffer et al. 2009). For example, many degraded lands are quite resilient to both further degradation and recovery. This definition of resilience focuses on the stability of the system. It ignores both the direction of change and whether stability is due to high resistance, or a tendency to recover, or return to the initial state, following a disturbance. Under this definition, both a paved asphalt surface or a concrete surface, and a field that has been cultivated for 50 years, would be resilient to tillage. The paved surface is highly resistant to perturbation by a tillage implement, while the structure of the historically cultivated soil will return to its previous state within a year.

Soil scientists generally argue that it is important to retain the distinction between resistance and resilience (Lal 1997; Seybold et al. 1999). This is similar to how the terms are used by engineers and physicists. The distinction is maintained for two reasons. First, soils may be resistant and resilient to one type of disturbance, while being only resistant, or resilient, to another. For example, relatively flat, deep soils, with uniform loamy fine sand texture throughout the profile, tend to be both resistant and resilient to water erosion. They are resistant due to both low slope and high infiltration capacity. They are resilient because the loss of several centimeters from the soil surface has little impact on relatively static soil properties; however, the loss may have a significant impact on dynamic properties such as soil organic matter content and nutrient availability. These same soils typically have low resistance to wind erosion due to their texture.

The second reason for maintaining the distinction between resistance and resilience is that the management and economic implications of resistance and resilience are quite different. The long-term costs of unsustainable land management practices are much higher in a system that is resistant but not resilient to degradation than in one that is resilient but not resistant. Ironically, however, agronomists have traditionally focused on degradation resistance rather than resilience. For example, a field that is losing 5 tons of soil per year is perceived to warrant more attention than one that is losing 10 tons, even if the 5 tons/year field is much more resilient than the 10 tons/year field. Economically, the net present value of conservation practices on the 5 tons/year field would likely exceed those on the 10 tons/year field.

A distinction is made between resistance and resilience in the following section. “Resilience” is defined as the rate and extent of recovery. Except where noted, we use the terms to refer to resistance and resilience to degradation.

22.2.2 Climate Change Adaptation and Resilience

Most climate change adaptation strategies are being designed to minimize or eliminate the negative impacts of climate change at the local level by changing the cultivar, crop, or management practice. Adaptation may also seek to compensate for production losses by exploiting positive impacts of climate change in areas of increased rainfall or longer growing seasons. Climate change adaptation strategies often include a resilience element. However, they are generally limited to considering the resilience of the system to changes in precipitation or temperature. They do not consider how these changes may be affected by current or potential future degradation resistance and resilience of the land itself.

22.2.3 Degradation Risk, Discount Rates, and Net Present Value of Investments in Climate Change Adaptation

Returns on investments in climate change adaptation are measured relative to a baseline of "no action." This baseline is generally defined as decreasing, stable, or increasing production solely as a function of climate change. However, all changes in management practices also have the potential to result in a change in degradation risk. An increase in degradation risk reduces the anticipated return on investment by increasing the discount rate. This is because investors must "discount" the net present value of a climate change investment based on the risk that the investment may be negated by soil degradation. A similar logic applies to climate mitigation and carbon markets have often discounted the value of carbon sequestered in soil. Discounting is based on uncertainty about its persistence (Stavins 1999; Marland et al. 2001). Increasing soil resilience can increase the net present value of climate change adaptation investments by reducing degradation risks.

22.2.4 Types of Risks

Adaptation investments must consider risks directly associated with a change in climate, such as increased drought frequency or intensity. However, they must also consider the following: (a) future degradation risk based on projected climate change for current land use, (b) risk of land use change, and (c) degradation risk based on future resistance and resilience resulting from new land use.[1]

[1] This paper provides a strategy for increasing returns on climate change investments by considering the potential impact of each of these risks on sustainability.

22.2.5 Livelihood Security

Overall birth and fertility rates continue to surge upwards while cereal production in Sub-Saharan Africa continues to stagnate due to land degradation, limited access to inputs, and declining capacities of natural resource governance structures. The World Research Institute reported that fertility rates in Sub-Saharan Africa are over five times the global replacement-level fertility rate (Searchinger et al. 2013). These rates put pressure on an already compromised land base to produce food and forages beyond its current capacity. Soil degradation reduces soil carbon stocks via runoff and erosion, decreased surface vegetation (spatially specific), and increased sedimentation. This reduction in soil carbon, and its resulting impact on soil quality, has obvious implications for crop yield. Demonstrated empirical links between soil degradation and direct pastoralist livelihood relationships are limited. However, existing studies reveal clear negative impacts on human nutrition (Searchinger et al. 2013) and household incomes (Scherr 2000), and an increased reliance on foreign food aid (Mafongoya et al. 2006; Millennium Ecosystem Assessment 2005), as a result of declining crop yields and livestock forage production. Moreover, these impacts and the dynamic feedbacks among them often weaken existing social safety nets that have been developed over time. These safety nets previously provided resistance to social change and human resilience to environmental shocks (Alinovi et al. 2007). Thus, climate-induced soil degradation can also intensify other dynamic feedback loops involving human and livestock migration patterns.

22.2.6 Human and Livestock Migration

Soil degradation, when coupled with livestock production, forage accessibility, and plant-water availability impacts, can also force dryland pastoralists to search farther for available forage. Often, they must cross private and publicly held lands to do so. As a result, direct competition for resources in these land areas can lead to increased competition, which in turn results in violent conflicts. Some empirical debate exists about the direction of the relationship between natural resource degradation and violent conflict (Bergholt and Lujala 2012). Links have been established between soil degradation and increased human migration (Gray 2011), which can increase the occurrence of violent conflicts in specific areas (Mkutu 2001). As land tenure systems in global drylands continue to convert communal ownership to individual or select group ownership (Peters and Peters 2012), pastoralists are challenged to secure access to these lands prior to introducing their livestock to available pasture. In some cases, pastoralists may choose not to secure this access to private lands. Rather, they opt to move their livestock to safer, but often more marginal, pasture as a way to avoid violent conflict. These areas often include soil types with low degradation resistance, and the move may lead to irreversible damage.

Current estimates from the International Organization for Migration are that between 25 million and 1 billion people will be displaced by 2050 due to climate change and soil degradation (Laczko and Aghazarm 2009). As suggested above, the migration of pastoralists can also increase degradation in the areas where they settle. Importantly, a share of this migration occurs because many rural pastoralists must increase their incomes regardless of the reduced soil quality and environmental change this causes (Gray 2011). Nevertheless, as soil degradation intensifies in global drylands, there are increasing incentives for pastoralists to consider long-term migration as an effective strategy for adaptation. As noted above, while migration to fertile land may seem an effective adaptation to localized soil degradation, this practice often aggravates or initiates violent responses from the citizens of the host environment. This is especially true in areas dominated by the resource-dependent and often politically marginalized rural poor (Alscher 2011; Nie 2003).

22.2.7 Violent Conflict

Global crises reflected by violent conflict, human suffering, and civil war have often been described as being "wicked by design" (Nie 2003). Violent conflict is driven by a suite of biophysical and socioeconomic components (Fig. 22.3). The existence of conflict increases resource dependence and migration, thus resulting in more degradation. Contrary to popular development and conflict mitigation theories of the 1990s, Brunnschweiler and Bulte (2008, 2009) illustrate that there is no "resource curse" that condemns resource-rich nations to a legacy of internal conflict. Instead, it appears that the opposite is a more accurate picture, as revealed by their empirical test of the relationship between increased resource abundance and subsequent reduction of the likelihood of civil war. Thus, soil degradation can be defined as an obstacle to peace in dryland communities, and soil conservation may be heralded as a valid conflict mitigation strategy.

Soil degradation results in increases in food insecurity and changes in human and livestock migration patterns. These socio-political responses in turn weaken the structures of traditional governance among pastoralist communities and effectively reduce their capacity to manage future conflict. This weakness can be seen clearly in the Maasai land and culture struggles in the Laikipia plateau of north-central Kenya (Mkutu 2011). The changing and extended movements of people and their livestock were traditionally established through cooperation with neighboring communities. As the traditional governance structures among those communities deteriorate, conflicts that arise can go unchecked and unregulated, further weakening the governance structures responsible for managing peace (Berger 2003). Ultimately, the consequences of violent conflict and war further contribute to continued soil degradation and reduced environmental quality.

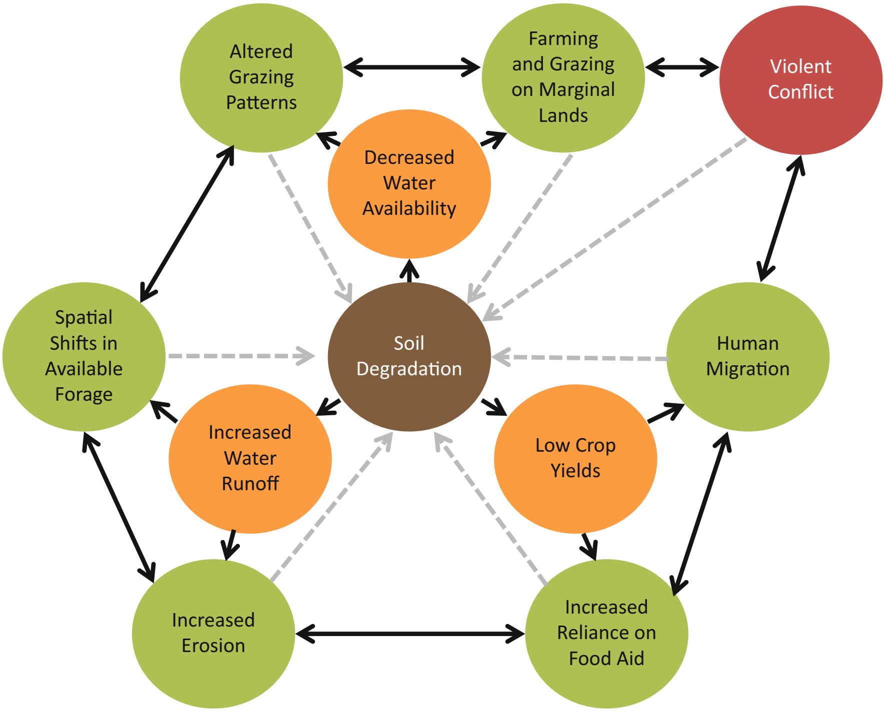

Fig. 22.3 Soil degradation and social stability feedbacks leading to potential violent conflict

22.3 A Strategy for Maximizing Return on Climate Change Adaptation Investments in Drylands Based on an Understanding of Soil and Ecosystem Resilience

This strategy includes seven steps, which are completed for each landscape unit in the context of the surrounding landscape:

1. Determine current potential productivity based on soils, topography, and existing climate conditions.
2. Determine future potential productivity based on soil, topography, and climate change scenarios.
3. Rank landscape units based on predicted change in potential productivity.
4. Determine risk of land use change.
5. Determine degradation risk with and without land use change.
6. Rank each landscape unit based on degradation risk with and without land use change.
7. Determine priorities for climate change and soil conservation investments.

Data needed to complete a quantitative analysis for this strategy are rarely available. However, qualitative analyses can be very useful for predicting the relative return on investment in climate change adaptation and soil conservation for different parts of a landscape, region, or nation. The subsections below describe each of the steps, followed by a case study of northern Namibia.

22.3.1 Step 1. Determine Current Potential Productivity

General predictions for a region can be obtained using the online Food and Agriculture Organization's Global Agro-ecological Zoning Tool (GAEZ) (FAO 2013). This tool is based on the land evaluation framework first published in 1976 and updated in 1996 (FAO 1996). It allows users to predict production for a wide variety of crops under low, medium, and high scenarios. It uses relatively coarse-scale soil, climate, and topographic layers. Consequently, while it is appropriate for general predictions for an area, it cannot be used at the field scale except in areas with exceptionally homogeneous soils and topography, such as lake plains.

A field-scale tool currently under development will allow users to predict potential production levels based on simple inputs to a mobile phone (Herrick et al. 2013b). This tool will initially use similar models to those used by the FAO GAEZ tool, but based on soil texture, color, and depth information provided by the user for the specific location of interest. Future versions will integrate local knowledge and production information gathered from the users themselves. It is being designed to complement the GAEZ tool, which down-scales global information by up-scaling local information and linking it with the global information provided by the GAEZ tool.

22.3.2 Step 2. Determine Future Potential Productivity Based on Soils, Topography, and Climate Change Scenarios

The GAEZ tool allows users to predict future production using down-scaled, pre-loaded climate change predictions generated under a variety of climate change scenarios. These climate change predictions can also be used to run field-scale models.

22.3.3 Step 3. Rank Landscape Units Based on Predicted Change in Potential Productivity

Where available, absolute values of potential productivity changes should be used.

22.3.4 Step 4. Determine Risk of Land Use Change

The risk of land use change should be assessed for the individual landscape unit in the context of landscape to regional scale trends. It should take into account social and economic factors. In areas where the agricultural frontier is expanding onto increasingly less productive and resilient lands, it should consider the probability that an economic threshold will be reached prior to a degradation threshold (Fig. 22.4).

22.3.5 Step 5. Determine Degradation Risk with and Without Land Use Change

At a minimum, the risk of soil erosion should be evaluated. Soil erosion usually results in the loss of both soil nutrients and a reduction in soil water available to plants, which is associated with a reduction in infiltration capacity. Soil erosion may reduce or increase plant-available-water-holding capacity depending on soil profile characteristics, including texture and structure. Soil organic matter loss, soil compaction, salinization, drainage, and declines in soil nutrient availability are additional soil degradation processes that may also be evaluated.

22.3.6 Step 6. Rank Each Landscape Unit Based on Degradation Risk with and Without Land Use Change

This is a necessarily subjective process due to the multiple types of degradation and uncertainty associated with each. Multiple experts, including local knowledge experts, should be consulted.

22.3.7 Step 7. Determine Priority for Climate Change and Soil Conservation Investments

In addition to changes in potential production and degradation risks, this analysis should consider the degradation impact on potential production and whether or not it can be reversed. It should also consider uncertainty in the predictions. Application of the precautionary principle (Kriebel et al. 2001) must be balanced with the recognition of the reality that it is impossible to eliminate degradation risk from virtually any agro-ecosystem. Instead, the goal should be to minimize the risk of

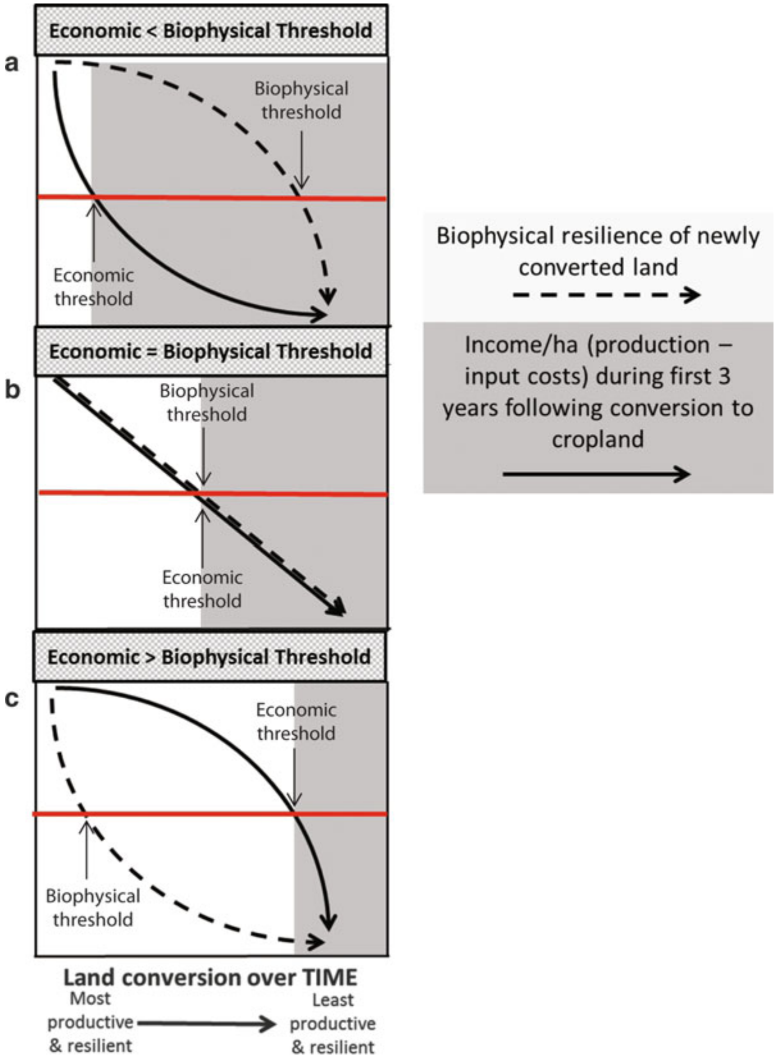

Fig. 22.4 Land conversion based on economic and biophysical thresholds. (**a**) When remaining (not yet cultivated) lands are beyond an economic threshold, but can be sustainably converted, land conversion will not occur for economic reasons. (**b**) When the economic and biophysical thresholds are equal, land conversion may occur for economic reasons before land (with high probability of crossing a biophysical threshold) is converted to cropland. (**c**) When the economic threshold is higher than the biophysical threshold, land conversion is likely to occur for economic reasons before land (with high probability of crossing a biophysical threshold) is converted to cropland (Modified from Herrick et al. 2012)

irreversible degradation of the most productive lands by intensifying production on the most productive and resilient soils, and targeting soil conservation interventions to highly productive, low resilience soils.

22.4 Case Study: Northeastern Namibia

22.4.1 Biophysical Description

Woodlands cover the majority of land in northern Namibia. Relatively small areas of deep loamy alluvial soils are interspersed in a matrix of deep eolian sands (Fig. 22.5; Table 22.2). Many of the fine-textured soils are associated with natural drainages, while others occur as isolated patches in upland landscape positions and associated ephemeral playas. These patches of relatively fine-textured soils are typically less than 100 ha in size and may be as little as 1 ha. They are clearly visible in satellite imagery. Annual rates of precipitation in the region average 500–600 mm, with most precipitation occurring during the November to March growing season. The mean temperature is 22 °C.

22.4.2 Land Use

Grazing is the dominant land use, and fires, both natural and anthropogenic, are relatively common. Small-scale subsistence agriculture is expanding. Loamy soils are highly preferred because they are more fertile, thus requiring fewer nutrient inputs, and because of their higher plant-available-water-holding capacity. Local farmers consider water-holding capacity a critical factor for determining whether or not a crop can be successfully produced during drought years.

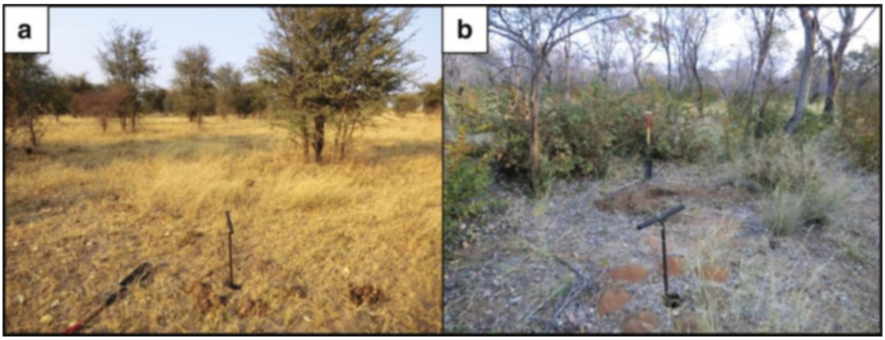

Fig. 22.5 Loamy (**a**) and sandy (**b**) soils in northeastern Namibia (see Table 22.1 for more information)

Table 22.2 Namibia case study based on data from two locations approximately 120 km west of Rundu, Kavango, Namibia. Current land use is livestock grazing

	Potential production						Priority[a]	
Landscape unit and example locations (see Schrader et al. 2013 for additional site data)	Current	Net change in potential production with climate change (rank)	Degradation risk for current land use (rank)	Potential future land use	Probability of land use change in next 20 years	Degradation risk for potential future land use (rank)	CC	SC
Flat loamy 17.7361°S 18.4908°E	High	1	2	Annual cropping	High	2 (high resistance, moderate resilience)	High	High
Flat sandy 17.76545°S 18.48805°E	Low	2	1	Grazing with annual cropping during wet years	Moderate	1 (low resistance, high resilience)	Low	High

[a]*CC* Climate Change, *SC* Soil Conservation

22.4.3 Climate Change and Impacts on Potential Production

Most climate change models predict that northern Namibia will become hotter and drier, and that rainfall events will become less frequent. This suggests that climate change adaptation must focus on increasing plant-available-water capture and storage, particularly for those lands that are undergoing conversion to cultivated agriculture.

22.4.4 Interpretation

Climate change adaptation should focus on more productive, loamy soils (Table 22.2). While potential productivity of all soils will be negatively affected by climate change, loamy soils are far more productive than sandy soils.

Soil conservation efforts, however, should be practiced on both types of soils. Northern Namibia's landscapes were formed by wind erosion and deposition interacting with alluvial processes that are part of the larger Okavango system. This system covers northwestern Botswana, southern Angola, and northeastern Namibia. The dominant soils in this system are classified as Ferralic Arenosols (Jones et al. 2013). Current studies are evaluating the risk that the cultivation of these landscapes may lead to regional destabilization.

22.5 Applications and Conclusions

The strategy described here can be applied on multiple scales to address a wide variety of objectives. An individual landowner may use it to decide where to intensify production or which land areas should be prioritized for soil conservation. Governments and development organizations can use it to identify those parts of a country that are vulnerable to climate change and soil degradation, and where the processes are likely to reinforce each other. In particular, climate change adaptation funds are likely to increase over the coming years. We suggest that the allocation of funds be made with consideration to the issue of soil resistance and resilience.

22.6 A Footnote: Application of the Strategy to Test and Document Tools for Increasing Resilience

The strategy presented for maximizing return on climate change adaptation investments in drylands is based on an understanding of soil and ecosystem resilience, and can be used to ensure that new systems for increasing resilience are rigorously tested and documented. Rigorous testing requires appropriate experimental controls, and in many cases, it is impossible to randomize the selection of experimental treatments and controls, due to the nature of innovation and the dissemination and adoption of advanced production systems and management practices. This does not, however, preclude the use of experimental controls, which should be as close as possible to the treatments in their potential productivity based on soils, topography, and climate conditions. While this is best done by a trained soil scientist, the Land-Potential Knowledge System (LandPKS) currently under development will allow even individuals with limited knowledge of soils to select paired controls based on land potential (Herrick et al. 2013b).

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