# Desertification, Drought, Poverty and Agriculture: Research Lessons and Opportunities

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**About ICARDA, ICRISAT, the DDPA and the Global Mechanism**

ICARDA and ICRISAT are nonproft international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR). They focus on sustainable agricultural development for the dryland poor. They also convene a global, multi-institutional partnership known as the Desertification, Drought, Poverty and Agriculture Consortium (DDPA) to provide research contributions towards the objectives of the United Nations Convention to Combat Desertification (UNCCD). The Global Mechanism was established by the UNCCD to promote actions leading to the mobilization and channeling of financial resources to developing countries to combat desertification. To learn more about us, visit www.icarda.org, www.icrisat.org, www.ddpa.net and www.ifad.org/gm .

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# Executive Summary

Desertification is a complex and multi-faceted phenomenon, as reflected in its definition by the United Nations Convention to Combat Desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activities". But what is land degradation? It too is complex, including biodiversity, soil health, water resource, landscape and agro-productivity dimensions.

The difficulty in defining desertification has complicated efforts to measure and combat it. Nevertheless, the fight against desertification confronts many real and serious issues such as persistent dryland poverty, recurrent droughts, eroding soils and shrinking market opportunities for smallholder farmers and herders who live far from the coastal gateways of commerce.

The poor are the most dependent on agriculture in the drylands, so they are hit hardest by desertification and drought. They are frequently blamed as agents of land degradation through the phenomenon of 'soil mining'—growing crops and grazing livestock without replacing the nutrients and ground cover that are removed, due to their limited financial means. This blame may be misplaced. The poor frequently initiate sustainable land management practices, especially when markets for higher-value crops emerge—as long as the right technologies, infrastructure and policies are in place. Their ability to invest in the future is undermined, though by policies that subsidize food imports, place taxes on the agricultural sector to support urban priorities, and neglect rural infrastructure and institutions.

Rising populations imply increasing food demands which may be difficult to meet without intensifying farming systems. The challenge is to intensify in a sustainable manner. An integrated view of agricultural and natural ecosystems is critical, because the poor depend on both, and each affects the viability of the other.

Dryland environments are fragile. Their vegetative cover is sparse; when removed through overgrazing or excessive tillage, exposed soils quickly erode and lose fertility, and the surface-sealed soils cause water to be lost as runoff. Sustainable solutions that preserve and enhance soil cover and organic matter such as mixed crop-tree-livestock systems, water harvesting and conservation, and the judicious use of manure and inorganic fertilizers at economically-optimal rates are showing success in many countries. Often these investments reduce rather than increase smallholder's risk.

Rather than simple, widely-applicable 'magic bullet' solutions, sustainable development in the drylands will require holistic and diverse interventions customized to the needs of different localities. Research and development should create prototypes and options that can be selected from and tailored to fit local needs. Since this requires close partnership, local institutions (formal, informal, governmental, non-governmental, private sector) should all be engaged to expand the reach of international institutions.

These types of solutions are knowledge-intensive, so improved systems for knowledge exchange will be vital. To be valued and adopted, interventions should capitalize on the wealth of local knowledge about sustainable dryland agriculture. They should be appropriate to and respect the traditions, values, resources and comparative advantages of local agriculturalists and their communities.

### *Priorities*

Six areas are high priorities for research to combat dryland degradation:

1. Increase understanding of the nature, extent and severity of desertification, drought and dryland degradation, and develop more effective ways to measure and monitor it;
2. Study institutions and policies, both formal and informal and across scales (international, national, local) that constrain or foster sustainable dryland development, seeking win-win-win (growth/equity/sustainability) solutions or minimizing tradeoffs;
3. Understand ecosystem dynamics, treating agricultural and natural environments as interdependent, and identify ways to increase the carrying capacity of the drylands without narrowing their biodiversity, soil and water resources or undermining their resiliency;
4. Genetically manipulate crops, trees and livestock to improve adaptation, stress tolerance, product quality and other valuable traits;
5. Build on dryland traditions of diversification to develop additional income-enhancing agricultural options such as new crop, tree and livestock choices (both indigenous and introduced from elsewhere)—accessing new market opportunities to raise farmer incomes while rewarding more sustainable land management; and
6. Improve the understanding of and modalities for the exchange of information, knowledge, expertise, tools, and solutions in ways that engage the poor and address their needs.

### *Dryland success stories*

The world has become accustomed to grim depictions of the drylands as hopeless zones of perennial misery, hunger and conflict. Tragedy and chaos grab attention. Meanwhile, much quiet progress has been made. Success stories that deserve greater recognition include:

- Cooperative management by thousands of herders to restore degraded rangelands across a three-million hectare area in eastern Morocco;
- The creation of community-based organizations and negotiated action plans to improve land management in the degradation-prone drylands of the Masreq and Maghreb countries of North Africa and the Middle East;
- The improvement of durum wheat management systems and varieties in the drylands of Syria;
- More than 100,000 severely-degraded hectares in the Central Plateau of Burkina Faso and Niger recovered for agriculture by smallholders using the zaï technique of breaking holes through the hardened soil crust and applying manure to stimulate the natural recovery of vegetation;
- Nimble responses of Nigerian dryland farmers in the Gombe area to shifting market opportunities over a 100-year period, belying the common assumption that dryland smallholders are inflexible or incapable of change;
- The spread of small-scale irrigation systems across the inland valleys of northern Nigeria and southeastern Niger, raising and securing incomes through vegetable and off-season production;
- The persistence and adaptability of Senegalese farmers during the 1970s/80s/90s when they were battered by major policy shocks including the repeated withdrawal and reinstatement of groundnut support policies, structural adjustment, subsidized food imports that handicapped

their efforts to compete in urban markets, a major currency devaluation that wrecked export markets, and severe recurrent droughts;

- The recovery of the degraded Machakos, Kenya area despite high population pressure as farmers responded to growing market opportunities in Nairobi by investing in soil rehabilitation and diversifying into higher-value crops;
- Forest recovery through community management in Tanzania, replacing a centralized approach that had disempowered and alienated the inhabitants of these areas;
- The rehabilitation of more than 50,000 hectares of degraded hillsides in Ethiopia through terracing and tree planting; also, major income gains from community-managed Eucalyptus woodlots;
- Increases in maize drought tolerance in varieties that are rapidly spreading across Southern and Eastern Africa; and
- Multiple improvements in pigeonpea in dryland India, raising yields by 57% through new disease resistance and raising farm incomes by 30% through shorter-duration varieties and production practices that enabled multiple cropping.

### *Conclusion*

Recent studies have challenged the common assumption that investment in the drylands delivers lower payoffs than in favorable areas. Those findings suggest that the relative neglect of the drylands in the past has probably left major gains unrealized. The dryland poor have demonstrated their eagerness to learn about and invest in new technologies and practices that help them grow their way out of poverty. They look to the research and development community to help them achieve this aspiration.

## Introduction

Desertification, defined by the United Nations Convention to Combat Desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activities" (UNCCD 1995), is a major global concern. The USA 'Dust Bowl' during the 1930s dislocated and impoverished many thousands. The collapse of the Soviet Union revealed land degradation on a large scale in the Central Asian drylands caused by inappropriate, mechanized over-farming (Holzel et al. 2002). The diversion of water flowing into the Aral Sea for crop irrigation during the Soviet era triggered catastrophic desertification over a large area (Saiko and Zonn 2000).

The limited arable land resources of North Africa/West Asia zone are being pressured by overgrazing combined with extension of the cropped area (Abahussain et al. 2002), and by salinization caused by dam and irrigation systems, such as in the Nile Delta (Juo and Wilding 2001a and 2001b). Dryland degradation is thought to be widespread in Sub-Saharan Africa. Northern China, Australia, northeastern Brazil, the Caribbean Islands, and many other dryland areas have experienced damage from deforestation and overgrazing in the drylands. Even Europe is not exempt; degradation is a significant issue across its driest, southern Mediterranean zone (Garcia Latorre et al. 2001; Yassoglou 2000).

As the major use of land in the dry areas, agricultural systems play a critical role in desertification and its frequent companion, drought. The poor in developing countries are especially hard-hit by these scourges. This paper reviews the historical context and dynamics of desertification to identify agricultural research and development priorities for combating them in the 21st century.

## Desertification: historical overview

The degradation of land is thought to have contributed to the decline of major civilizations (Juo and Wilding 2001a and 2001b). Climate change combined with deforestation and social upheaval may have played a part in desertification around fertile Mesopotamia (Lowdermilk 1953; Weiss et. al. 1993), but governance and development policies may also share some blame (Barker 2002). A long-term drought may have caused the decline of the Mayan empire (Haug et al. 2003). Deforestation and erosion, and possibly climate change may have triggered social conflict that brought Easter Island's thousand-year Moui culture to ruin (Bahn and Flenley 1992), although diseases and slavery brought in by European settlers are also a plausible explanation (Rainbird 2002).

The first usages of the term desertification emerged in the 1920s/30s to express a concern that the Sahara might be marching southwards, swallowing Sub-Saharan Africa in its wake (Aubréville 1949; Stebbing 1938). Other urged caution though as more careful studies could not substantiate an advancing Sahara (Anglo-French Commission 1973; Helldén 1991; Mortimore 1989). Nevertheless, the frightening image of a creeping burial by sand triggered urgent calls for action from international aid organizations, donor countries and governments (Swift 1996).

As the 'advancing deserts' narrative faded in the absence of convincing data, attention shifted towards human actions that were demonstrably degrading lands, such as deforestation, over-cultivation, over-grazing, and salinity-inducing irrigation practices, frequently aggravated by droughts.

### The United Nations Convention to Combat Desertification (CCD)

The CCD provides a modern framework for international cooperation against desertification. In response to severe droughts in Africa during the late 1960s/70s in Sub-Saharan Africa that killed approximately 200,000 people and millions of animals, the United Nations organized the first global Conference on Desertification (UNCOD) in Nairobi in 1977, which produced an ambitious Plan of Action. Although it did not generate the hoped-for global commitment of resources, it rekindled a sense of urgency that carried forward to the United Nations Conference on Environment and Development (UNCED, or the Earth Summit) in Rio de Janeiro in 1992.

The Earth Summit raised the profile of the problem by catalyzing negotiations for an International Convention to Combat Desertification (CCD). The CCD was especially favored by developing countries who saw it as more closely aligned with their development priorities than its more environmentally-oriented sister Conventions on Biodiversity and Climate Change, also initiated at that Summit. The CCD entered into force in 1996 and had been ratified or accepted by 191 nations by early 2004.

The CCD urges a wide range of development efforts and policy reforms, supported by increased scientific and technical cooperation (Horstmann 2002; Humphreys and Carr 2001; Hoven 2002; UNCCD 1995). The United Nations reiterated its call for support for the CCD in its Millennium Declaration, signed by 189 Member States (UN 2000 and 2001). The 2002 Johannesburg World Summit on Sustainable Development also reinforced the call to action.

## The Dynamics of Desertification

### Defining Desertification

The term 'land degradation' is central in the CCD's definition of desertification (see Introduction). However the concept of land degradation is itself beset by complexity (Mazzucato and Niemeijer 2000b). Some drylands undergoing degradation can also be viewed as in transition to a different state of stable equilibrium that some may interpret as desirable or at least inevitable, such as from agropastoral systems to intensive but sustainable farming that can support larger populations (Leach and Mearns 1996; Tiffen 2002; Tiffen and Bunch 2002). The encroachment of unpalatable bush species across rangelands may degrade their economic value but provide greater erosion protection to soils. The erosion of soils in one area may enhance them in another through deposition, and so on.

This is why definitions of land degradation are difficult to express in simple and universal terms. They tend to depend on the context and perspective of the observer. The perspectives of local land users, for example may be different from those of international agencies.

A concept frequently used is to consider degradation to be measurable in terms of 'loss of productivity'. However the degradation of some valuable resources such as biodiversity and some soil properties may not result in productivity loss in the short, medium or even longer term. Furthermore, it is often difficult to untangle productivity changes attributable to underlying degradation processes from those which may have been caused by unrelated factors such as policy decisions favoring one crop or location versus another, technological change, or shifts in import/export opportunities and market access (Mazzucato and Niemeijer 2000b).

## What causes desertification?

Befitting the complexity of the desertification and land degradation concepts, a wide range of causal factors are involved. The CCD cites climatic, ecological, poverty, governance, and other drivers (UNCCD 1995).

In accordance with images of barren, desertlike conditions, much past attention has been paid to soil degradation. It should be kept in mind though that the CCD definition looks more broadly to also include other resources such as biodiversity, ecological processes, and hydrological resources.

Soil degradation begins with the removal of vegetation. Unprotected, dry soil surfaces are readily eroded by rain and wind, leaving infertile lower soil layers that bake in the sun and become an unproductive hardpan. Sand dunes may form where the blown surface material accumulates. Losses of vegetation threaten biodiversity and habitat for other species.

Removal of the protective cover of vegetation, in turn can be driven by a number of factors, alone or in combination, such as tillage for agriculture; drought; over-grazing; removal of crop residues for feed/construction use; deforestation for fuelwood and construction materials; and inappropriate irrigation practices that lead to salinity.

These proximate causes are themselves triggered by a wide range of root causes, some of which originate outside the drylands. They include climatic shifts; growing populations that add pressure on land resources; policies that encourage frontier expansion and mechanized land-clearing; inadequate/ambiguous property and tenure rights that trigger farmers to exploit or restrict investment in commonly-held lands; landlessness and an inequitable distribution of assets; inadequate infrastructure; limited market access; inappropriate technologies; and insufficient research and development support.

## Drought

The role of drought bears special mention. Drought is a natural cycle of stress and renewal inherent to these regions (Breman and Wit 1983; Niemeijer and Mazzucato 2002a; Rasmussen et al. 2001; Tiffen and Mortimore 2002), but increasing agricultural pressure on the land aggravates its consequences (Akhtar-Schuster et al. 2000). Drought depletes vegetative cover and may lead to human actions (such as overgrazing) that propel drylands more rapidly towards a desertlike condition. At what point, though should long-duration drought be reclassified as climate change, and its land-degrading consequences be included within the umbrella of desertification (Hulme 2001; Humphreys and Carr 2001; Norton-Griffiths and Rydén 1989)?

## Climate change

A major new threat is climate change (Hillel and Rosenzweig 2002). Modeling results suggest that dry areas could become hotter and drier, especially semi-arid Africa and South Asia (Parry 2002). If climate change increases the frequency and/or intensity of droughts, it would aggravate desertification. Given the uncertainty in the models, other outcomes are also possible; recent observations suggest that the Sahel is re-greening (UNEP 2003), although the reasons are not understood and it appears that more factors than just rainfall are involved.

## Measuring the extent of desertification

Because of the breadth, complexity and dynamism of phenomena reflected within its definition, desertification is difficult to measure (Eswaran et al. 2001). Observations of resources and processes such as vegetation, soil, water, ecosystems, climate and terrain rarely lead to a single simple conclusion. Where should desertification maps draw the line between ‘state’ and ‘process’, i.e. the area already degraded, versus the area thought to be at risk of degradation if droughts continue or if other vulnerabilities not yet exploited actually do materialize (Oldeman and Van Lynden 2001)?

These ambiguities should be kept in mind as estimates of the extent and distribution of desertification are reviewed. After UNCOD, the then-new United Nations Environment Programme (UNEP) commissioned ‘The Global Assessment of Human-Induced Soil Degradation’ or GLASOD, coordinated by the International Soil Reference and Information Centre (ISRIC) (Bridges and Oldeman 1999). An important output was the World Atlas of Desertification (Middleton and Thomas 1997). In a separate effort, areas where people are highly vulnerable to desertification (based on soil and population characteristics) were estimated by US Department of Agriculture scientists (Reich et al. 2001).

Since few countries had sufficient quantitative data on land degradation, the GLASOD estimates were mainly based on expert judgments that were necessarily subjective. The authors of these studies as well as other reviewers urged that they be used cautiously (Berry 1983; Oldeman et al. 1991; Oldeman 1994; Oldeman and Van Lynden 2001; Stoorvogel and Smaling 1990; Wood et al. 2000; UNEP 1997; Swift 1996; Toulmin, 1997).

Based on these UNEP-GLASOD studies, the CCD Secretariat indicates that desertification threatens about 30% of the earth’s terrestrial surface and already affects approximately 70% of the earth’s agricultural drylands, home to more than 250 million people in over 110 countries, with another one billion people at risk, and possible economic losses in the range of US$42 billion annually (UNCCD 1995). The USDA vulnerability study (Reich et al. 2001) estimated that 46% of Africa’s land area is vulnerable to desertification, which is nearly the entire cultivable dryland area; the 22 million people living on Africa’s desert margins are the most threatened.

Given the difficulties in defining and measuring desertification, it is not surprising that these estimates have proven controversial (Leach and Mearns 1996; Mortimore, 1989; Niemeijer and Mazzucato 2002a; Thomas and Middleton 1994; Swift 1996; Toulmin 1997). This controversy is more than just a matter of academic debate. It reflects uncertainty about the nature, scope, magnitude and extent of the problem and the best ways to tackle it (Kurzinger 1998; Pagiola 2001; Swift 1996; Toulmin 1997; Toulmin 1995). These uncertainties have made priority-setting and planning difficult, and have restrained investment by the developed world in the CCD agenda. Yet all agree that the suffering caused by desertification and drought in the developing world must be alleviated.

## Policies, institutions, economic trends and desertification

Structural adjustment of national economic policies during the 1980s/90s made some developing-world goods and services somewhat more globally competitive. However, agricultural subsidies in Europe and the USA still significantly impede developing-world access to global markets, depressing their agricultural sector and their ability to invest in new sustainable technologies (McCalla 2002). Structural adjustment also led to higher input prices in local currency in many developing countries (Hazell 2001). This has constrained farmer’s use of fertilizer and other purchased inputs, aggravating the depletion of soil fertility.

Falling farm productivity encourages people, especially the young, to migrate out in search of better options. This increases farm labor costs and disrupts social structures, including the adoption of new technology.

Many rural development policies and institutions in the developing world are subject to conflicting pressures, for example between urban, farming and pastoralist constituencies. The tradeoffs as well as synergies among agricultural productivity, human welfare and environmental sustainability are especially challenging (Ruben et al. 2001). Often the only politically viable option is to defer the changes needed to arrest land degradation.

Efforts to develop rational dryland use plans have been hampered by the lack of resources and capacities for their effective implementation (Wood and Rydén 1992). Many rural institutions are under-funded or being dismantled in fulfillment of structural adjustment commitments, creating uncertainty in basic support systems such as credit and marketing. On the other hand, the emergence of new institutions and institutional relationships among government and international agencies, NGOs, community organizations and the private sector is a positive trend.

Much remains to be learned about how societies respond to desertification and drought. Traditional and local institutions have often been neglected or even discouraged by government agencies that sought to introduce modern policies and practices from the developed world. For example, rigorous seed laws demanding extensive testing and varietal homogeneity are at odds with traditions of local seed exchange and the maintenance of genetic diversity on the farm in many developing countries (Gisselquist 1997). They also delay improved seeds from reaching the farm and increase its cost, or render the seed system infrastructure unsustainable.

It is increasingly realized that local institutions can be effective agents for sustainable land use if they are understood and supported rather than superseded (Mazzucato and Niemeijer 2002). To support these institutions, a better understanding is needed of the conditions that lead to their sustenance. The risk of not doing so is that well-intentioned external interventions could go awry. Efforts to privatize land for example can disrupt customary tenure arrangements and inter-ethnic relations leading to social conflict and negative impacts on the environment (Turner 1999).

The context-specificity of policy and institutional effects are also not well understood (Pender et al. 1999). Lessons learned from research often tend to be site specific and not replicable to other regions. Finding ways to scale up to the national development level and/or scaling out to other communities is a major challenge (and opportunity).

Traditionally, dry areas received limited amounts of development assistance due to a perception that the return on investment will be greater in more favorable environments. However, recent studies in India and China have found greater returns to public research investments in the drylands, than in more favorable areas (see 'success stories' section). Rural infrastructure, such as roads to reduce the costs of inputs and marketing, along with education, communications and health care are essential for helping farmers improve their competitiveness and profitability (Lewis 2003).

International fora and conventions help countries make policy choices about dryland degradation (Hannam and Boer 2001). A number of important milestones include the Stockholm Conference on the Human Environment (1972), The World Soil Charter (1982), The World Commission on Environment and Development (1987), the Earth Summit (1992), the UN Millennium Declaration (2000) and the World Sustainable Development Summit (2002). These provide avenues for desertification issues to enter into top-level discussions and decision-making.

## Poverty and desertification

Does poverty cause land degradation and desertification, or vice-versa? Or are they parts of a feedback loop? As the discussion below will illustrate, this issue is also controversial. Whether the poor are major agents of desertification or not, it is clear that they suffer especially from its consequences because they are highly dependent on the land's productivity for their livelihoods (Hazell et al. 2002).

### *Exploring the soil mining narrative*

The risk of drought and consequent crop failures along with financial constraints discourage the poor from investing in their lands (fertilizer, organic matter, fallows etc.) Without inputs, the soils are 'mined' of their native fertility and protective cover (e.g. trees being removed for firewood). As those lands become nonproductive, the poor expand onto additional, often more marginal lands in order to meet basic needs, impoverishing those soils as well. In this way they relentlessly mine until the soil resource is exhausted (Bationo et al. 1998; Buresh et al. 1997; Cleaver and Schreiber 1994; Eswaran et al. 2001; Gruhn et al. 2000; Matlon 1987; Sanchez et al. 1997; Sanders et al. 1996; Smaling et al. 1997; Steiner 1996; Stoorvogel and Smaling 1990; Van der Pol 1992; World Bank-FAO 1996).

Doubts have been raised about the generality of this soil mining narrative, though. Some have questioned the robustness of the extrapolations of research-plot data and models to regional and continental scales that underlies this narrative (de Ridder et al. 2004; Mortimore and Harris 2004; Niemeijer and Mazzucato 2002b). They point out that it does not account for the wide diversity of smallholder practices and the large number of ecosystem interactions on typical farms. They note that dryland farmers are keenly aware of the importance of maintaining productivity and coping with drought, and are skilled in indigenous techniques for doing so (Dahlberg 2001; Mazzucato and Niemeijer 2000b; Mortimore and Harris 2004; Niemeijer and Mazzucato 2002a and 2002b; Reij et al 1996; Scoones et al. 1996; Scoones 2001b; Scoones and Toulmin 1998).

### *Mining, or borrowing?*

Soils near the homestead in Africa are often favored with fertilizer and manure for careful cultivation of the highest-value and most important food security crops (Mazzucato et al. 2001; Scoones 2001a). Farmers use fertilizer when they can afford it. Fields further from the homestead are typically cultivated with less or no fertility amendment and lower yield expectations, to supplement the homestead crops on an opportunistic basis.

The manure applied to the homestead fields represents a transfer of nutrients from grazing lands, while inputs of fertilizer are a net inflow of nutrients. Farmer interviews have shown that they recognize the depletion that is occurring in their outer fields and will correct when it is affordable and remunerative to do so (Scoones 2001a; Tiffen 2002). These adaptive responses suggest that farmers are 'borrowing' soil fertility from one area and lending to another, to be paid back later when they are able. Viewed in this way, static estimates of continental nutrient balances seem too coarse a tool upon which to interpret farmer behavior or to formulate research, development and policy directions.

A fertility borrowing perspective implies a different set of research and development imperatives. Research is needed to evaluate the capacity, resilience, and balance dynamics of these resource pools.

How long can the borrowing go on without permanent damage to the outfield and grazing land resources? How can farmers be assisted in their natural inclination to rehabilitate these areas? The fertility borrowing concept highlights the opportunity to build on farmers' responsiveness to markets by introducing infrastructure, policy reform and technology interventions that reduce the costs of, and increase the rewards from fertilizer use.

### *The role of the non-poor in land degradation*

While the role of the dryland poor in land degradation is complex, there is less debate about the impacts of some non-poor land users. Mechanized state farms in the ex-Soviet Union, large-scale dryland farming in the USA, and modern-day nomads in the Middle East who truck large flocks of sheep out to graze along the desert fringe, have often degraded resources more rapidly than the poor could have (Bliss 2001; Durikov and Winckler 2001; Holzel et al. 2002). Government policies and incentives often trigger this form of degradation (e.g. requirements and incentives for land clearance to establish land ownership). Deforestation in Haiti causes great suffering for smallholders, but its origins trace to a ravenous export lumber industry run by colonial slave masters in the 18$^{th}$ century (Weiner 2004).

### *Are poverty and degradation inevitable in desertification-prone areas?*

Similar to the soil mining concept, it has been suggested that poverty, overpopulation and land degradation create a self-reinforcing downward spiral leading to ever-greater misery (Cleaver and Schreiber 1994). This scenario stands juxtaposed against the 'induced innovation' model of Boserup (1965), which proposes the opposite dynamic. In the latter scenario, as populations grow markets tend to develop and land becomes more costly relative to labor. These factors motivate investment in more intensive, yet sustainable land management in order to reap the benefits of the enlarged market opportunity.

Both scenarios have been reported under different situations (Pender 1998). Cases of the downward spiral were described by Durning (1989), Leonard (1989), Lopez (1998), Kates and Haarmann (1992), Mink (1993), Ram et al. (1999) and White and Jickling (1995). Induced innovation has been reported by Leach and Mearns (1996), Mortimore and Adams (1999), Templeton and Scherr (1999), Tiffen (2002b), Tiffen et al. (1994), Tiffen and Mortimore (2002), and Wiggins (1995).

Comparing the downward spiral vs. induced innovation evidence, it appears that outcomes largely depend on how well societies adapt to rapid population growth, globalization, market development, technological change, climate change, and agro-ecological conditions (Heath and Binswanger 1996; Jodha 1998; Lele and Stone 1989; Kuyvenhoven and Ruben 2002; Lopez 1998; Mazzucato and Niemeijer 2002; Mortimore and Harris 2004; Niemeijer and Mazzucato 2002a; Pender et al. 2001a; Prakash 1997; Scherr 2000). Intensification does not necessarily imply that poverty will be reduced; if more labor-productive systems are not employed, then wages cannot increase or may decrease due to the increased availability of labor. Common threads in success stories include exploitation of local comparative advantages (soil, climate, biodiversity, labor, etc.); access to technologies that can increase land and labor productivity faster than population growth; and improved access to growing markets (Hazell and Haddad 2001; Mortimore 2004; Pender, 1998; Pender et al. 2001b).

Tiffen (2002a) considers the induced innovation model to have potentially wide applicability across Africa. From the original state of virgin land, extensive agropastoralism is sustainable as long as population density remains low. But as populations and land pressure increase, degradation and poverty ensue. If access to markets emerges, as it will tend to do when increasing populations coalesce into urban centers, people will respond and rehabilitate their lands as they intensify. Reinforcing this dynamic, Tiffen (2003) notes that rural population growth is currently leveling off in many parts of Africa while urban growth is accelerating.

## Risk and new technology adoption

Dryland farming is inherently risky due to drought. Since price supports, crop insurance, futures trading markets, irrigation and other risk-reducing strategies are unavailable to smallholder farmers, they have only limited means for financially cushioning against risk, such as off-farm employment, family networks, and moneylenders (Anderson 2001). Nevertheless, smallholder farmers are willing to take considered risks, particularly when they are confident that a new technology will succeed and when they have access to reliable markets that can absorb their produce (Mortimore and Harris 2004; Sanders et al. 1996; Abdoulaye and Sanders 2003; Tiffen 2002).

Improvements in prediction technology may help cushion against drought risk in the future (Wilhite 2002). Changes in oceanic and atmospheric temperatures, for example correlate with the El Niño phenomenon, and can be combined with other climatic modeling data to provide increasingly accurate predictions of the likelihood of drought. More effective drought prediction can help governments prepare and cope (Hulme 2001; Oba et al. 2001; Palmer and Anderson 1994; Hastenrath 1995; Goddard et al 2001). Other types of information can also reduce risk, such as market prices, pest forecasts, and crop cultivation advice. The challenge is to implement these initiatives in ways that reach and benefit the poor.

Economic and marketing interventions can also buffer against risk. The grain crops of the African drylands, millet and sorghum are not traded internationally so seasonal production cycles have a large impact on prices received by farmers. Through individual or collective storage and marketing, farmers can release grain gradually into the market to keep prices at a stable and remunerative level. Problems in jointly managing stores must be avoided, though. In Niger, pilot studies testing a 'warrantage' approach ask farmers to place grain in collective stores; loans are issued with the grain as collateral to meet farmers' immediate needs while in storage. Farmers have been willing to try this approach when the risk/reward advantage has been clearly demonstrated through field trials and pilot studies (Abdoulaye and Sanders 2003).

## Soil fertility, fertilizer and risk

Low soil fertility is common in the drylands. Dry, hot conditions limit vegetative growth, resulting in low soil organic matter content compared to wetter environments (Bationo and Buerkert 2001). Human activities exacerbate this problem. Vegetation is often removed for fuel, feed and construction purposes, instead of recycling into the soil. This drives organic matter and nutrient contents even lower, depressing productivity further. Soils that are low in organic matter are less effective in retaining nutrients in plant-available forms and are more susceptible to compaction and erosion.

Innate deficiencies of phosphorous and nitrogen are characteristic of the Sahel, for example—a zone where nutrient deficiencies are often more growth-limiting than water supply (Bationo et al. 1998; Breman 1992). There is ample evidence that fertilizer can increase dryland productivity significantly when rainfall is adequate, but will it be economically and environmentally sustainable over the long term (Sanders et al. 1996)? Because of low organic matter and low cation exchange capacity many Sahelian soils are weakly buffered, raising the risk of soil acidification through the use of ammonium-based fertilizers (Bationo and Buerkert 2001). The addition of organic matter such as livestock manure remarkably moderates these effects, but these areas are not capable of producing enough manure to meet the need (Breman 1992).

Researchers are investigating whether the targeted addition of small amounts of fertilizer to the planting hole might overcome this dilemma (Aune et al. 2004; Gérard et al. 2001). Small amounts are more affordable for farmers, give an economically optimum (though not biologically maximum) response, and if placed in the root zone of these widely-spaced crops rather than uniformly distributed, result in more efficient uptake. If fertilizer could stimulate the growth of more crop biomass than is needed for human and livestock purposes, the remainder would become soil organic matter. Higher soil organic matter content in turn would improve plant growth and fertilizer response the next season, and so on in a self-reinforcing upward spiral (Bationo and Buerkert 2001).

Degraded wastelands can also become a source of soil organic matter. In Burkina's Central Plateau the increased production of fodder due to adoption of the zaï technique to rehabilitate degraded lands has enabled farmers to increase livestock numbers, generating more manure to deposit into the zaï holes (sometimes with small amounts of inorganic fertilizer as well) in a self-reinforcing cycle (Kaboré and Reij 2004).

Fertilizer is commonly thought to increase risk in dryland farming, but in some situations it may be risk-neutral or even risk-reducing. Phosphorus and shorter-duration millet varieties in Niger, for example cause crops to grow hardier and mature earlier, reducing damage from and exposure to drought (Gérard et al. 2001; ICRISAT 1985-88; Sanders et al. 1996; Shapiro and Sanders 1998; Shapiro et al. 1993). A key constraint though is the availability of fertilizer and the incentive for adopting fertility-enhancing crop rotations in these zones (Thomas et. al. 2004).

## Diversification – key to mitigating risk

Diversification is central to dryland agriculturalists' strategies for reducing and hedging against risk (Sanders et al. 1996). Nomadic pastoralism exploits the mobility of livestock to diversify location in response to drought and the depletion of grazing resources (Behnke et al. 1993). Crop farmers also diversify, mixing their crops, varieties, planting times, splitting their fertilizer applications, and other agronomic adjustments to reduce risk (Brouwer and Bouma 1997). Diversification into off-farm employment is also very important in the drylands; it can account for a major portion of rural household income (Mortimore 1998; Sanders et al. 1996; Tiffen 2003). Diversification also enhances sustainability and biodiversity (McNeely and Scherr 2003). Many advocate building on the dryland tradition of diversification to open new income-earning opportunities (Farías 2001; Hazell and Haddad 2001; Kerr 2002; Ndikumana et al. 2002; Pasternak and Schlissel 2001; Sanchez 2001; TAC 2000; Tengberg and Stocking 2001).

### *Agroforestry potential*

For example, the relative lack of past attention paid by research and development organizations to dryland agroforestry compared to more humid zones suggests the possibility of major unexploited opportunities (Leakey 1999). Kessler and Breman (1991) caution though that there are tradeoffs that must be weighed, such as competition with crops for water and nutrients, and with more palatable herbs for grazing area.

Trees, shrubs and specialty crops have historically played a vital role in dryland agriculture in developing countries (Hulse 1996; von Maydell 1990). Trees are preserved on farms because they are valued for goods and services such as fuelwood, construction material, fodder, medicines, cosmetics, enhancing soil fertility, and shade (Leakey 2001a, b). In the drylands of West Asia and North Africa, trees have long been domesticated and orchards (e.g. olive, citrus, pistachio) are ubiquitous. Sheep and goats are grazed between the trees. Trees are highly regarded by African farmers as well. Contrary to expectations that urban expansion would result in deforestation, tree density increased in the surroundings of Kano, Nigeria from 1972 to 1985 as farmers protected and planted trees to meet the demands of the growing fuelwood market (Cline-Cole et al. 1988).

Agroforestry research can build on these indigenous traditions. Valuable tree species can be domesticated through farmer-participatory selection for desirable traits (Leakey 2003a; Mulas et al. 1999). Some examples of dryland trees and shrubs valued by farmers and holding potential for increasing application are from the genera *Acacia* (wattle, gum arabic, ana tree), *Adansonia* (baobab), *Agathosma* (Buchu), *Aspalathus* (redbush or rooibos tea), *Azadirachta* (neem), *Boscia*, *Ceratonia* (carob tree, locust bean), *Cyamopsis* (cluster bean - guar gum), *Eucalyptus*, *Hibiscus* (roselle, bissap), *Mangifera* (mango), *Moringa* (miracle tree), *Olea* (olive), *Parkia* (locust bean), *Pistacia* (pistachio), *Phoenix* (date palm), *Sclerocarya* (marula), *Tamarindus* (tamarind), *Vitellaria* (shea butter), *Warburgia* (pepperbark tree), and *Ziziphus* (apple of the Sahel). There are many others that have hardly been investigated or fit into niche environments within the drylands such as oases or riverine areas (Leakey 2001a; von Maydell 1990). The International Agroforestry Centre ranked the following as priorities for domestication in the Sahel: *Adansonia digitata, Vitellaria paradoxa, Parkia biglobosa, Tamarindus indica and Zizyphus mauritiana* (Leakey 1999).

Rangelands can also be diversified, providing alternatives to the overgrazing of fragile native vegetation. Drought-tolerant fodder trees and shrubs accumulate biomass over the rainy season, serving as 'fodder banks' to help animals survive the dry season. Cacti (*Opuntia*), saltbushes (*Atriplex*), and wattles (*Acacia*) (Houerou 2000) have been successfully introduced in West Asia/ North Africa. Spineless cactus (*Opuntia ficus-indica*) is showing promise in large plantations in Algeria and Tunisia; the higher water content of cactus aids in feed intake and digestion (Nefzaoui and Salem 2002). Agricultural wastes on-farm or from urban processing centers (straw, rice bran, date pulp, whey, brewer's grain, wheat bran, corn gluten etc.) can be compacted into nutritious 'feed blocks' and trucked to the drylands (where transportation is affordable), sparing the need to graze fragile vegetation. These approaches need to be accompanied by steps to avoid environmental damage potential from hazards such as overtillage for sowing range species, soil and water supply degradation around feed and watering stations, and the unwanted spread of alien species which could affect native biodiversity.

Diversified crops, shrubs, trees, rangelands, and other farm operations can also catalyze diversification in local agro-enterprises (Leakey 2003b). New ways to process and market foods create new opportunities for a wider variety of income-generating enterprises, creating a ripple effect that multiplies the benefits broadly through rural communities (Hazell and Haddad 2001).

Diversification of markets is also important. Specialty crops that could tap foreign markets could become valuable earners of hard currency for the poor, e.g. the case of Rooibos (redbush) tea in

South Africa (Rogers 2003). For export markets though, the entire production, processing, handling and marketing chain must be efficient since international markets demand consistent, high and uniform quality and dependable supplies. A case in point is gum arabic produced mainly in Sudan, Chad, and Nigeria. Gum arabic is highly regarded as an emulsifying agent by the soft drink, confectionery, pharmaceutical and paint industries. However, variability in supplies and quality caused these industries to seek and develop alternatives such as starch-based compounds (Macrae and Merlin 2002). Research and development is needed to help restore the competitive position of products like gum arabic, and open new opportunities.

## Ecological concepts and issues

### Ecosystem goods and services

The dynamics of agricultural and natural ecosystems are deeply intertwined in the drylands, particularly in the developing world (Wood and Rydén 1992). Farmers, pastoralists, hunters, gatherers and fisherfolk draw resources from both components, and affect them as well. Agricultural systems are dependent on goods and services generated by natural ecosystems such as wild foods, grazing, timber, fuel, fiber, medicines, pollination services to crops, soil fertility regeneration, water storage and supply (drought and flood control), carbon storage, air and water purification, climate moderation, tourism potential, and cultural values among others. Natural ecosystems are quickly degraded by agricultural activities such as frontier expansion, intensive logging, overgrazing and pollution.

Worldwide, ecosystems provide goods and services that would cost an astonishing US$33 trillion annually to replace, almost twice the value of all goods and services produced by people (Alonso et al. 2001). The potential for improvements in agricultural ecosystems to provide more desirable ecosystem goods and services is substantial and justifies increased public financing (FAO 2002).

Given these interdependencies, research and development efforts must take an integrated view of both natural and agricultural ecosystems (see 'integrated ecosystems approach' section). Approaches to rural development that integrate the sustainable provision of natural ecosystem goods and services with agricultural development have has recently been termed 'eco-agriculture' (McNeely and Scherr 2003).

### Fragility

Drylands are often characterized as ecologically fragile. The loss of scarce vegetation and soil carbon, for example increases vulnerability to soil erosion, as described earlier. Traditional pastoral livestock systems under low population density place bearable loads on this ecosystem. Nomads shift their herds according to location and seasonal variations in forage quantity and quality, and water supplies. As populations increase and as droughts set in these areas are quickly degraded, as observed in some locations in the Sahel (Breman 1992; Norton-Griffiths and Rydén 1989) and in the Horn of Africa (Akhtar 1998; Ndikumana et al. 2002).

### Carrying capacity

'Carrying capacity' is an intuitive concept for assessing ecosystem fragility (Wood and Rydén 1992), but its simplifying assumptions must kept in mind. Geerling and de Bie (1986) define carrying capacity as "a level of equilibrium in a system between the availability of an element, limiting a given type of system use, and the degree of use of this element." Agriculture is the dominant human 'system use' in the drylands of the developing world, and carrying capacity limitations may constrain its productivity and sustainability.

For the Sahel, assuming no external inputs, Denève (1994) estimated that two hectares of cultivable land are the minimum required to support one person (with three-fourths of the land lying fallow in any given year to regenerate soil fertility). Dividing this land requirement into the total quantity of arable land available in each Sahelian country (assuming no wildlands would be left unexploited), he estimated the approximate maximum carrying capacity and current status for each country. Countries with relatively high population densities relative to arable land endowments such as Burkina Faso had already exceeded this definition of carrying capacity. Niger would have been in a similar situation except for its close ties to the economy of Nigeria, releasing some pressure from its land and generating remittances that are reinvested in the farm back home. Coastal countries such as Senegal and Mauritania also benefited from the 'escape valve' of interaction with other economies through their seaports. Breman (1992) estimated that Burkina Faso, Mali and Niger were within their carrying capacities by the 1970s, but prolonged droughts over the subsequent 15 years had plunged these systems into a downward cycle of degradation.

Carrying capacity examples that exclude inflows, outflows, and climatic variations may be of limited relevance in today's world, but the exercise illustrates how such limits might be reduced or increased (Breman 1992). By increasing inflows and reducing wastage, for example dryland carrying capacity could seemingly be elevated significantly. Such changes often trigger follow-on effects in ecosystems, however, including degradation that could reduce carrying capacity. Research is needed to understand and predict these potentials and risks, and find *sustainable* ways to increase carrying capacity.

## Water use efficiency

Water is the defining constraint of the drylands. Drought avoidance and coping strategies are imperative such as choosing drought-tolerant crops, low plant densities, water conservation and water harvesting. In the drylands of Ethiopia and Sudan, smallholders have evolved indigenous techniques for water harvesting (Krüger et al. 1996; Niemeijer 1999). Burkina Faso, with World Bank assistance encouraged the construction of earthen and stone contour dikes across 60,000 hectares in the heavily-degraded Yatenga area during the 1970s/80s (Sanders et al. 1996). India has placed sustainable watershed development at the top of its dryland agriculture agenda (Farrington et al. 1999).

While water shortage is a constant concern, much of the water which *is* available is not efficiently used (Wood and Rydén 1992; Breman). In the Sahel, degraded soils often exhibit impeded water infiltration so much is lost as runoff. Breman (1992) notes that natural vegetation in the 450 mm annual rainfall zone of the Sahel utilizes only 15% of the incident precipitation. The remainder is either lost to evaporation, as runoff or remains in the root zone unutilized. When soil fertility is improved, water use by vegetation can increase to 50% and productivity can increase fivefold, greatly lifting the carrying capacity of the land. In the Mediterranean drylands, one plant breeding strategy has been to increase cold tolerance so that crops will use more of the rainfall that falls during the mild winters before evaporation losses become significant.

## Biodiversity

The stress placed by agriculture on the land goes beyond food production. Conversion of natural lands to agriculture or rangelands can reduce biodiversity through dynamics such as habitat elimination and fragmentation, collateral species damage from pesticides, and overgrazing (Akhtar-Schuster et al. 2000; McNeely and Scherr 2003; Pagiola 2001; Sutherland and Scarsbrick 2001). Often this type of collateral damage to natural ecosystems feeds back to reduce the carrying capacity of agricultural systems. For example, less-palatable, drought-tolerant and annual species are replacing perennials in Eastern Sudan, leading to shortages of livestock feed (Akhtar-Schuster et al. 2000).

Ecosystem interactions need to be better understood in order to avoid triggering such unintended consequences. How can dryland farmers and rural communities be helped to recognize when they are on the brink of losing biodiversity resources that underpin their livelihoods? Is biodiversity degradation gradual and reversible, or are there 'tipping points' beyond which it accelerates with self-generated downward momentum?

'Keystone species' that are important for the health and survival of many other species are tipping-point indicators; they need to be identified and their dynamics understood (Krogh et al. 2002). What are the requirements to initiate biological succession processes that will lead to the recovery of other species? Much needs to be learned in particular about below-ground biodiversity such as the roles of soil fungi, bacteria and invertebrates in ecosystem health (Pagiola 2001).

## Trees

Dryland areas exhibit a sparse but important tree component (hence the term 'parkland') that contributes importantly to ecosystem functions. With their year-round root system and longer duration of canopy cover, trees increase the total ecosystem capture and recycling of nutrients, water and sunlight (Ong 1996). Tree canopy coverage of about 15-20% appears to be an optimum balance in the Sahel for total productivity (Breman and Kessler 1995).

Trees can break hard soil layers and stabilize sand dunes and hillsides as well as restore soil fertility, as witnessed in the Keita project in Niger (Carucci 2000), in local practices of farmers in Burkina Faso (Sawadogo et al. 2001) and in eucalyptus plantings and the REST hillside restoration project in Ethiopia (Jagger and Pender 2002; Pender et al. 2002; Relief Society of Tigrai 2002). Degraded land can be progressively reclaimed through a replacement series mimicking the natural progression from pioneer species to a multi-story, tree-based climax phase (Leakey 2003a). As trees become established and the species mix becomes more complex, new niches are created that are colonized by additional unplanned biodiversity such as insects, birds, and fungi, both above and below-ground (Leakey 1999).

## Indicators of ecological health

Given the complexity of dryland ecosystems, researchers have sought to identify simple, practical indicators they can measure to discern ecosystem health and trends. More work is needed in this area. Soil organic carbon influences many soil properties and drives many processes associated with both agricultural production and ecosystem services (Bationo and Buerkert 2001). Soil carbon trends are thus an important indicator of ecosystem health. Other practical indicators include vegetative biomass and cover; livestock numbers and management patterns (feed sources for example); human populations; and observable resource flows into and out of the drylands such as movements of humans, animals, and capital.

Satellite remote sensing technology combined with geographical information systems are emerging as powerful tools for monitoring vegetation trends. Technological advances are making them increasingly affordable (House et al. 1999). Direct measurements of basic ecological processes such as evapotranspiration are becoming practical and inexpensive enough to be repeated frequently at high resolution (Rosema 1993).

## An integrated ecosystems approach

The preceding discussion leads to a conclusion that integrated consideration of both the agricultural and natural components of dryland ecosystems is essential for sustainable development. An integrated ecosystem approach has been advocated for the drylands by the United Nations Convention on Biological Diversity (UNCBD 2004) and for the UNCCD process in particular the World Resources Institute (White et al. 2002).

Integrated ecosystem thinking has its heritage within the natural resource management (NRM) approach that has received so much attention during the past quarter-century (McNeely and Scherr 2003). It began by advocating more ecosystem-friendly approaches to crop production, such as conservation farming and intercropping. Farmer participation was added as the farming systems approach emerged. Steadily, an ever-wider panorama of natural and agricultural components were incorporated, as reflected in the descriptive phrases agroecology (Altieri 2002), agroforestry (Leakey 1999), and integrated natural resource management (CGIAR 2004).

The integrated ecosystem approach is a major departure from the reductionist, mostly biophysical approach of the past. These distinctions are outlined in Table 1. Historically, systems were simplified as much as possible in order to facilitate large-scale, often mechanized cropping. Issues were examined in isolation such as fertilizer and pesticide rates and responses. Attempts were made to minimize complex interactions, e.g. focusing on just a few crop species and homogenizing the soil fertility environment. The scale of system examined was often limited to a production field unit, excluding the surrounding landscape and ecosystem.

Integrated ecosystem thinking, on the other hand applies a systems orientation to address mosaics of different land use types within a landscape area. It considers resource flows and balances/tradeoffs among different uses. It looks beyond the production field to consider interactions with the adjoining natural areas within the larger landscape. Diversity and risk assessment are important. More complex processes such as ecological succession, restoration of native systems, different states of equilibrium, resiliency, and ‘tipping points’ receive attention.

## The management and sharing of information and knowledge

A particular dilemma for the integrated ecosystems approach, as for other integrative sciences is how to achieve wide impact when the problems and solutions require multifaceted interventions that tend to differ over time and space (Penning de Vries 2001). Generic principles may be too broad to be directly applicable in particular locations, and solutions derived in one location may not ‘scale up’ to apply directly in other locations.

**Table 1. Distinguishing features of conventional vs. integrated ecosystem approaches to agricultural research and development.**

| Aspect | Conventional Approach | Integrated Ecosystem Approach |
|---|---|---|
| Perspective | Natural ecosystems seen as input suppliers (land, fertility etc.) for current or future commodity production | Natural and managed ecosystems viewed as part of one interdependent whole, providing a wide range of goods and services |
| Products | A few commodities or products | A wide array of both managed and natural goods and services |
| Strategy | Maximize yield, production, and net present value by intensifying the use of land, labor, and capital | Optimize total ecosystem goods and services output over time |
| Methodology | Reductionist: high-resolution measurement of a small number of factors | System-oriented, including both quantitative and qualitative assessments with close attention to interactions, flows, asset balances, tradeoffs |
| Approach to diversity | Reduce diversity for more predictable results, more targeted interventions, and greater economies of scale | Take advantage of diversity to exploit niche potential, meet a wider range of needs, preserve future options, and reduce total system risk |
| Scales of work | Field, political and ownership boundaries | Ecosystem, community and landscape, societal plus biophysical |
| Role of science | Applied science focused on biophysical resources, geared towards specific technology outputs | Combine biophysical with social and policy analysis, create prototypes, toolkits and models of development processes for local adaptation |

The improbability of simple, wide-scale, 'magic bullet' solutions to desertification requires that scientists and development practicioners seek ways to manage such complexity. Knowledge and expertise lie at the heart of integrated solutions. Research and development workers need to find better ways of compiling, reconfiguring, customizing, targeting and sharing knowledge (Seré 2001; Speth 1994). Changes in communication behaviours will be required. Research and development practitioners must share knowledge more effectively and efficiently than before. When people are convinced that they have a substantive role in devising and implementing change, they are more likely to contribute to knowledge flows.

The peoples living in desertification-prone areas hold traditional and local knowledge that is valuable but difficult to access due to geographical isolation and differences of language, culture, and communication patterns. Their knowledge has been ignored too often in the past. The CCD places a high priority on respect for and the application of traditional and local knowledge (Articles 16, 17 and 18.2 of the Convention). Conscious approaches are being developed to identify innovative farmers and foster farmer-to-farmer sharing and experimentation (Reij and Waters-Bayer 2001).

Information technology can play a complementary and synergistic role to these efforts. PC-based monitoring systems can receive and interpret meteorological satellite data, for example. The outlook for factors related to agro-climatic conditions, expected crop yields, marketing and price trends, and other important information can be relayed to farmers, traders and transporters quickly and in a manner targeted to local needs. This could help warn of impending droughts, improve the efficiency and competitiveness of markets, and empower the poor to obtain a larger portion of the benefits of agricultural growth.

Rural telecenters are one promising example (PANTLEG 1999; UNDP 1999). Wireless data transmissions provide a knowledge pathway that reaches even the most isolated villages. Farmers need not become computer literate or multilingual. Local community moderators serve as their interlocutors and link to information management professionals who can supply the information needed (Economist 2001).

## Pathways to impact

Since magic bullet solutions are unlikely, an integrated ecosystem approach must take a different strategy. Instead of fixed technologies, the main research outcomes are knowledge, expertise, ideas, strategies, methods, models and approaches. Portfolios of options are developed rather than recipe-like solutions.

Mechanisms are then needed to engage communities in their customization and deployment. The difficulty is the high cost of engaging with each community directly and uniquely. This is impractical given the limited quantity of research and development resources at hand.

The answer may lie in leveraging the communities themselves to play a greater role in their development. Participatory development methods are receiving much attention (Reij and Waters-Bayer 2001; Uphoff 2002). Closer partnerships with non-governmental organizations and other development agents can magnify the leverage of research and development institutions in ways that make 'mass customization' practical.

## Regional approaches to combating desertification

We now turn to the application of many of these concepts and principles around the world. Different regions of both the developed and the developing world are grappling with the effects of desertification and drought today. Similarities as well as differences in their strategies provide opportunities to share valuable lessons learned—while recognizing that their differing social, economic and ecological settings also imply important distinctions in approach.

### The North American Dust Bowl

Perhaps the best-known case is the Dust Bowl experience of the USA and Canada during the 1930s (Hurt 2001; World Bank 2003). European descendants migrated into the vast western drylands known as the Southern Plains beginning in the late 1860s. Both settled farming and free-range grazing were practiced. As cattle populations increased without restriction, overgrazing ensued. Tractorization during the first half of the 20th century led to intensive soil tillage, exposing ever-larger areas of the soil surface to wind and water erosion. Crops suited to wetter areas, such as maize and wheat were increasingly planted but were frequently devastated by an extended drought period during the 1930s, further reducing soil cover. Once exposed, the light prairie soils were easily blown by wind, creating a choking 'Dust Bowl'. Without farm income, many of the poor inhabitants were driven into bitter and degrading livelihoods as migrant labor (a nightmare famously captured in John Steinbeck's classic novel 'The Grapes of Wrath').

The Dust Bowl prompted massive interventions by the US government to rehabilitate the area and prevent this disaster from recurring. The response emphasized science and technology, the formulation and enforcement of ecologically sound land use policies, emergency and livelihood assistance, and the integration of population in the effort (Hurt 2001). This holistic approach included:

- Research into then-new sciences of soil conservation and range management
- Land policy changes (relocation of farmers and protecting the most sensitive grasslands)
- Grazing controls (controlling herd sizes according to land use suitability; fencing)
- Establishment of a soil conservation service to develop and implement conservation measures
- Increasing water supplies and water management, at both large and small scales (irrigation systems, on-farm practices)
- Development of better-adapted livestock and crop breeds (e.g. drought tolerance)
- Emergency aid and subsidies (price supports, rural relief services, and public works employment schemes)
- Infrastructure development (railways and highways)
- Effective extension services and vocational training

During the 1950s, droughts triggered a renewed wave of dust storms. However, residents and the government responded more rapidly than in the 1930s. Farmers in many areas increased their use of conservation tillage methods without waiting for government incentives. The result was that damage and suffering was much less than in the earlier period.

Notwithstanding this success, concerns persist about the sustainability of farming practices in the Southern Plains area (Stewart and Robinson 1997; World Bank 2003). Massive subsidies are needed to underwrite this land management package, and underground aquifers are being depleted at an unsustainable rate. Policies continue to be re-examined although change is often politically difficult and technically complex (McClure 1998).

## South America and the Caribbean: where the drylands know no borders

Drought and desertification plague significant areas in South America and the Caribbean, such as northeastern Brazil (Candido et al. 2002; Oliveira, M. de 2000), the Gran Chaco region crossing Argentina, Paraguay, Bolivia, and Brazil (Eger and Prem 2002), and several of the Caribbean islands. This illustrates the need for multi-country, trans-boundary cooperation. Rural areas such as these, however often lack political clout and scientific resources. NGOs have helped introduce important small-scale solutions in northeastern Brazil (Soccal 2000).

One of the most extreme examples of desertification is the small island nation of Haiti (Weiner 2004; White and Jickling 1995). It serves as a cautionary example to other countries of how wrong things can go – and what lies ahead if they slip down the same slope. Rampant deforestation caused by exploitative policies, poor governance and overpopulation have stripped its originally-forested land of protective cover, resulting in barren, eroded hills, widespread poverty, hunger and disease. Despite its crowded condition, insecure land tenure is not the immediate constraint to land rehabilitation in Haiti – poverty and governance issues are the overriding factors (Smucker et al. 2002). Nearby Jamaica is also undergoing rapid deforestation (Weis 2000).

## Sub-Saharan Africa: questioning prior assumptions

The Dust Bowl triggered worries among African colonial authorities that African agricultural practices might result in similar catastrophe (Anderson 1984; Swift 1996). This stimulated large-scale, authoritarian interventions during the 1950s-70s, most of which did not succeed. The reasons for failure are numerous (Bationo et al. 1998; Bliss 2001; Box et al. 1992; Chambers et. al 1989; Leisinger and Schmitt 1995; Marchal 1986; Mazzucato et. al. 2001; Mazzucato and Niemeijer 2000a; McIntire et al. 1995; Onyewotu et al. 2003; Pagiola and Holden 2001; Rochette 1989; Scoones 2001b; Scoones et al. 1996; Tiffen and Mortimore 2002). They include narrow, sectoral, centralized, authoritarian, and technocratic approaches; unrealistic capital and labor requirements; lack of access or affordability of required inputs; inappropriate technologies developed for non-African conditions; lack of congruence with and/or support from government priorities, policies, and incentives; insufficient infrastructure and institutions; lack of local community involvement and commitment; lack of awareness of, or disregard for local knowledge and values; incompatible land-tenure traditions; and inadequate training and communications. Often, several of these elements combined to doom a project.

Some phenomena that appear alarming to an outsider may be a result of misperception, different background experiences, and different value sets. Assumptions about rampant smallholder-driven land degradation are for example coming into question, as discussed earlier. Smallholders are well aware of land degradation (e.g. Bielders et al. 2001) and have evolved practices to combat it (Mazzucato et al. 2001; Prain et al. 1999; Reij and Waters-Bayer 2001; Scoones 2001a). Examples include soil and water conservation methods on the slopes of the Ethiopian Highlands (Krüger et al. 1996); adaptive techniques for nutrient and water harvesting in Sudan (Niemeijer 1999); and zaï holes to hold water and manure in the root zone to rehabilitate eroded hardpan soils in Burkina Faso (Kaboré and Reij 2004; Ouedraogo and Kaboré 1996). Increasing appreciation for the power of traditional and local knowledge led to more participatory project approaches during the 1980s/90s (Biot et al. 1995) that continue today.

A third-generation approach emerged in the 1990s that emphasized the role of policies and institutions, and the interrelationships between poverty, population growth and land degradation (Biot et al. 1995). Attention to these aspects arose from an increasing awareness of the linkages between poverty, land degradation, and hunger; and the consequences of structural adjustment programs and global trade policy liberalization.

### *Is land tenure an impediment to sustainable practices?*

Outsiders often see customary tenure systems and traditional and local practices as inefficient and land-degrading. This perception often excludes the total ecological cost of intensive farming, as a case study in Namibia illustrates (Hongslo and Benjaminsen 2002). International agencies have sometimes argued in favor of land privatization to reward investment, and many African governments have attempted to nationalize lands (Olulumazo 2000). These policies often conflict with traditions that share lands within the clan or ethnic group. Communal systems may be less productive in short-term crop production, but in better equilibrium with the longer-term management of the total ecosystem, including groundwater resources and downstream effects. A study in Mali found that communal pastoral systems produced 1.5 to 8 times more protein per hectare in milk and beef than did cattle systems in the USA and Australia, under similar climatic conditions – and without the use of fossil fuels (Breman and Wit 1983).

There is ample evidence that African smallholders do invest in the sustainable management of land even though formal land titles are not held. Customary systems often provide excellent tenure security. Several studies have found that the lending, renting, or even sales of land rights are possible in many customary systems, and enhance an efficient distribution of land resources and allows farmers to avoid overexploitation (Ouedraogo et al. 1996; Zeeuw 1997; Mazzucato and Niemeijer 2000b). Sanders et al. (1996), building on the views of Matlon (1991) and of Place and Hazell (1993) conclude that the absence of formal land titles is not a significant constraint to the promulgation of sustainable land management practices in semi-arid Africa.

A frequent point of friction in the use of common lands is the competition between cropland and livestock grazing. Actions to protect croplands from cattle, or to stabilize or settle nomadic peoples have triggered conflict. Attempts to compensate for the loss of the pastoral lifestyle by introducing modern fenced livestock methods in Botswana did not succeed in reducing risk or stabilizing livelihoods (Thomas et al. 2000).

Involving the local community in developing solutions, with particular attention to their customary tenure systems and their economic needs, is critical to success in Africa, as elsewhere (Bliss 2001; Lusigi 2001; Mani and Liebenthal 2001; Scoones et al. 1996; Seely and Wohl 2002). Yet, the community approach will not succeed in isolation; communities must also link together to coordinate their actions, and influence national policies and investments (Brandt et al. 2001).

## Beyond technology: communities, policies, institutions, and markets in West Asia and North Africa (WANA)

West Asia and North Africa have rapidly growing populations but very limited areas of arable land. This causes increasing competition between cropping and pastoralism for use of the scarce land resource. Irrigation potential is limited and near its full exploitation already. Environmental problems such as salinity, overgrazing, and excessive tillage are serious and widespread, and increasing under agricultural pressure (Abahussain et. al. 2002; El-Beltagy 1999; Oram 1998).

Droughts are a frequent threat. When drought strikes, crop yields fall and pastoralists are forced to sell their livestock at low prices because feed and water will be insufficient for the whole herd. Government actions to aid farmers and pastoralists suffering from droughts are well-intentioned but tend to be made permanent. When farmers and herders believe that the government will step in when they face difficulty, it creates an unwritten incentive to increase risk by intensifying production, which leads to dryland degradation. The wealthy tend to benefit the most from such subsidies (Hazell et al. 2001). Rainfall insurance (provided by the private sector) may be an alternative worth considering, because it would extend both the costs and benefits in proportion to the amount of protection desired by land users.

An international conference discussed ways to advance the triple goals of enhancing economic growth, equity, and environmental sustainability in the region (Oram 1998). It concluded that progress in four key areas is needed: market liberalization, property rights

reform, drought management, and appropriate technologies. Greater crop-livestock integration and rangeland rehabilitation were urged to increase sustainability.

The globalization of markets is a major challenge and opportunity for the WANA zone, given its proximity to Europe. The constraints of the drylands: intense solar radiation, high temperatures, low-quality water and barren lands—can conversely be viewed as competitive assets for certain purposes (Safriel 1999 and 2002). Sunlight can be used to produce energy and grow winter crops. Saline water can be used for aquaculture. The tourism potential of drylands can be developed. Diversification into new enterprises such as these could open new income-earning possibilities while strengthening the region’s competitive position.

## Central Asia and the Caucasus: mechanized desertification

The rugged dryland countries of Central Asia face drought and desertification risk on a wide scale, and have limited resources to combat it. The centralized planning and state farm system of the former Soviet Union wreaked environmental havoc as it introduced heavily-mechanized techniques transplanted from different settings, uprooting local traditions and ignoring local knowledge that had sustainably managed these areas for centuries (Casermeiro and Azhigaliyev 2001; Durikov and Winckler 2001; Holzel et al. 2002; Pavlov et al. 2001).

The environmental disaster of the Aral Sea basin (Mainguet et al. 2002; Saiko and Zonn 2000; World Bank 2003) is a nightmarish example of top-down planning. A scheme to achieve self-sufficiency in cotton production diverted massive amounts of water from the rivers flowing into the Aral Sea. Desiccation of the Sea zone triggered other processes such as salinization and pollution of waterways, the loss of native vegetation and biodiversity, and salt-dust storms, choking the ecology and economy of a vast area.

As a result, the newly-independent Central Asian countries face problems of salinity, erosion, pasture degradation, biodiversity loss, and losses of traditional knowledge. Historical dependence on the government for centralized action, and ambiguities in current governance and legal structures have inhibited individuals and communities from combating desertification (Durikov and Winckler 2001). Severe poverty, unstable political structures and violent conflict have weakened capacities to address environmental risks in some countries such as Afghanistan (Saba 2001). Paradoxically, the collapse of the Soviet system is enabling some natural ecosystems to recover, since many of the state-led mechanized activities have ceased (Holzel et al. 2002).

## Watershed Management – a unifying concept in South Asia

South Asia has a much higher population density than Sub-Saharan Africa, creating severe land pressures. A large proportion of India is arid or dryland. Landholdings along the Thar Desert are halving in size every 20-30 years as fathers split their land among their sons, increasing land degradation and food shortages (Ram et al. 1999). On the other hand, large populations provide inexpensive labor, skilled scientific and technical resources, and urban markets, which can lead to land rehabilitation under the right circumstances (see earlier discussion on 'are poverty and degradation inevitable in desertification-prone areas?').

Desertification and drought have long been concerns in India, and much research has been carried out (Rao et al 2000). As in Africa, though projects in the mid to late 20$^{th}$ century tended to take a techno-centric approach, yielding solutions that were often not well-suited to local circumstances and priorities.

Dryland development in India was heavily influenced by major Green Revolution successes with wheat and rice improvement in more favorable zones. However the lessons did not transfer well to the parched drylands. Constraints included an inability of farmers to make the needed investments in irrigation and other inputs, the non-availability of improved implements, inadequate credit facilities, poor roads and other infrastructural limitations. For example, many farmers were not interested in fertilizer responsive, higher grain-yield sorghums because their priority was on straw for livestock feed (Asokan et. al. 1998).

Recognizing the need for different thinking, the 'watershed management approach' has risen to prominence since the 1950s (Lobo and Samuel 2001; Samra and Eswaran 2000). Watershed-based development accelerated rapidly after the countrywide drought of 1987 through large-scale government projects. By the 1990s watershed development had become a focal point for rural development in the country with an annual budget of over US$450 million from numerous sources (Farrington et al. 1999). The watershed management approach is currently also gaining favor in dryland areas of neighboring Asian countries like Thailand, Vietnam, and China.

In assessing India's watershed development effort, Kerr (2002) found limited adoption of watershed interventions so far because many were not appropriately designed for the agronomic, socio-economic, and regulatory systems that these areas faced. For example, the broadbed-and-furrow making tool, designed for heavy, wet Vertisol soils in valley bottoms, found little adoption because it was too heavy and expensive (Joshi et al. 1998).

However Kerr noted increasing success since a shift to farmer and community participation had taken hold. Examining marginal lands in India, Fan et al. (2000a) found better returns on research and development than in irrigated areas (see 'success stories' section).

### Large-scale anti-desertification efforts in China

Desertification is considered a serious and increasing threat to one-third of China's area (Chen 2000; Zhao et al. 2002; Wang 1998; LiXian 2000; Sen et al. 2000; Bo 2001). The problem arises mainly in the dry northern zones where agropastoral systems have faced escalations of pressure from rapidly-increasing human populations, combined with state policies during the 1950s-80s that encouraged the expansion of croplands into these areas. Deforestation, the destruction of native grasslands through tillage for cultivation, and the drainage of wetlands have triggered large-scale soil degradation, environmental pollution, sand storms and floods.

China is combating desertification through its Western China Development Programme and its CCD-based National Action Program. Many effective control and rehabilitation technologies have been identified (LianQing and ZePing 2001). Although large, centralized projects have faced difficulties in other parts of the world, they appear to fare better in China. Satellite remote sensing systems provide early-warning indicators of desertification trends. The stabilization of sand dunes and reclamation of sandy areas, the re-vegetation of degraded rangelands (including aerial sowing), the control of grazing intensity and timing, water resource conservation, the creation of forage farms, the rehabilitation of eroded and salinized soils, and reforestation are all major activities being pursued.

The need for grass-roots buy-in and participation is increasingly recognized (LiXian 2000). The National Action Program includes a long-term, integrated strategy to encourage social participation, provide legal and institutional guarantees, promote policy reforms, and establish demonstration and pilot projects to combat desertification, both at national and provincial levels. China has committed to share its experiences internationally in areas where it has developed considerable strength, such as more effective soil regeneration techniques and early-warning indicators.

### The Australian Landcare approach and policy measures

Almost 75% of Australia is dryland. Australia's native biodiversity is unique but is diminishing under the onslaught of large-scale land-clearing, mechanized farming and ranching (Glanznig and Kennedy 2001). Government policies and investments are now tackling this crisis; recent laws such as the Environment Protection and Biodiversity Conservation Act trigger government involvement in any matter deemed to be of 'National Environmental Significance' and the formal listing of 'Key Threatening Processes' such as vegetation clearance.

Since the 1990s a community-driven sustainable development model that emphasizes broad societal participation has emerged, called Landcare (Sutherland and Scarsbrick 2001). Through their shared commitment to Landcare, communities engage with government, NGO, land owner, and private sector partners to take actions where their interests and capacities intersect. Due to its inclusive, non-partisan approach and government commitment and investment, Landcare has been a popular and successful initiative, now recognized by about 82% of the total Australian population (Lloyd 1999). Land Care, Bush Care, Coast Care, and similar associations agree to integrated principles and guidelines for the conservation and management of land, sustainable economic activity, support for social, aesthetic, cultural and heritage values, diversity, and sustainable development. Core elements of the Land Care model include:

1. A sustained, non-partisan, broadly-inclusive approach
2. Ownership by those involved
3. Science and technology to guide but not dominate the program
4. Private sector involvement and financial support
5. Combine agricultural and environmental objectives, not pitting one against the other
6. A bottom-up approach, from community to region, and from small to large-scale progression
7. Involving local schools and incorporating natural resource management in the curriculum so that land care is fostered into the next generation

An example of the success of this approach is in southwestern Australia, where the key desertification problem is too much water in some places and too little in others, often at the wrong times. Local community groups provided leadership in land use planning. Where water is in excess, drains were installed that fill check dams that provide water at other times or places as needed. Trees were planted to provide a means for utilizing deep moisture, and to act as shelter-belts. By intercepting water and managing it consciously, water quality has improved. Livestock carrying capacity of these areas has increased and a larger area is available for cropping as well (Lloyd 1999).

## Lessons learned – a summary

The purpose of surveying these regional experiences was to extract lessons that appear to have wide applicability. Here are some themes that appear to resonate across drylands everywhere:

1. Be holistic in approach, rather than sectoral, technocratic, or uni-disciplinary.
2. Form broad partnerships in order to access the wide range of skills and buy-in needed.
3. Be participatory: engage the affected parties from the beginning, and respect their priorities, values, traditional and local knowledge, and capabilities.
4. Embrace the diversity of needs and circumstances of different areas – avoid one-size-fits-all thinking.
5. Ensure government commitment to change: desertification is often an unintended byproduct of development policies.
6. Seek win-win solutions that support and build on land tenure customs rather than conflict with them.

7. Diagnose problems carefully and through dialogue with those living in an area, rather than acting on prior external assumptions about what may be happening.
8. Consider risk: new interventions should reduce or at least not increase the risk burden on the poor.
9. Economic motivation: ensure that interventions improve land user's economic circumstances so they will be motivated to adopt and sustain them; and that they have access to the capital and knowledge resources required.
10. Exploit local comparative advantages: develop opportunities that capitalize on the local climate, biodiversity, traditional and local knowledge, and other often-overlooked assets.
11. Resist short-term, reductionist 'project' thinking – desertification is a long-term process with many subtle effects (biodiversity degradation, the depletion of aquifers, downstream silting from improper watershed management, etc.)

These lessons are congruent with those that arose from a World Bank assessment of reasons for successes and failures of its natural resource management projects (Mani and Liebenthal 2001).

## Success stories in combating desertification

The drylands seem to be perennially troubled and unable to make headway. Conflict, hunger, drought, and migration situations attract headline attention and cause discouragement among many in the developed world. If the development effort is futile, why continue with it?

Yet there are numerous, significant, well-documented dryland development success stories that do not attract headline attention, even in the difficult settings of Africa. UNEP (1999) carefully reviewed claims of success in combating desertification, and identified *bona fide* success stories in dryland Burkina Faso, Cape Verde, Mauritania, Namibia, Nigeria, Senegal, and Sudan. Success stories typically reflect a combination of individual and community initiative, ingenuity and innovation supported by research and development aid. In many cases, the progress was (and is being) achieved in the face of daunting challenges such as climatic risks and policies that discriminate against the agricultural sector.

Success stories span the fields of soil and water conservation, irrigation, forestry, livestock and range management, community-based natural resource management, extension and research, and local institution-building. Indicators of success include long-term increases in productivity; increases in per capita income; increased drought resilience of rural production systems; increases in biodiversity; and high rates of return on investment. Some cases are described below.

Agricultural rehabilitation in the Central Plateau of Burkina Faso (1980-2002) was achieved through soil and water conservation, crop and livestock systems improvement, and increasing the organizational capacity of villagers (Kaboré and Reij 2004; Reij and Steeds 2003). Approximately 100,000 hectares have been contour-bunded to reduce water runoff. Soil fertility has been restored to tens of thousands of hectares of degraded land using the zaï technique of digging holes to retain manure and water in the plant root zone. Increased fodder supply enabled increased livestock numbers, in turn increasing manure supplies for raising soil fertility. Due to water harvesting efforts, groundwater recharge improved significantly; wells that used to run dry in the dry season now provide water year-round, an effect that cannot be explained simply by rainfall variation (Kaboré and Reij 2004). Farmers report substantial productivity gains and enhanced family food security.

Villagers perceive substantial reduction in the frequency of poverty in their communities, and reduced out-migration. The authors note that good governance throughout the period was also essential for success, and the 1994 devaluation of the CFA franc increased livestock values, helping motivate farmer investments.

The benefits of this innovation spilled over into Illela, Niger (1988-1995) in a powerful demonstration of the value of farmer-to-farmer sharing of ideas (Hassane et al. 2000; Reij and Steeds 2003). A modest development project ($1.5 million over eight years) sponsored Illela farmers' travel to Burkina Faso's Central Plateau. By seeing what their neighbors had done, the Illela farmers became convinced that the benefits were worth investing in. They implemented the zaï technique on their degraded land and were delighted when the practice saved them from the 1990 drought. By 1998, 9,000 hectares had been rehabilitated, equaling about 15% of the cultivated area. Farmers even began buying degraded land, confident they could restore it; land that was previously considered worthless now saw rising market prices. The practice continues to spread even though project support ended in 1995.

The recovery of the degraded Machakos district in Kenya, reported by Tiffen et al. (1994) is a well-known success story. Land quality improved despite a fivefold increase in population pressure from 1930 to 1989. Farmers responded to growing market opportunities in nearby Nairobi by implementing soil and water conservation practices, adopting new and more diverse cropping systems, diversifying their operations, and reinvesting gains from off-farm employment into their farm operations.

Farmers in the Gombe area of northern Nigeria showed remarkable agility in response to market and demographic shifts over the period 1900-2000 (Tiffen 2002). From a low-population density pastoral lifestyle, populations grew rapidly, constraining cattle movements. They adapted by becoming a leading center of groundnut production after World War I, when river navigation made it possible to market their groundnuts to the export outlets of the south.

After World War II, government policy encouraged cotton production and they quickly became leading producers, manufacturing plows and other innovations that apparently doubled yields and quadrupled production over the decade 1951-61. When cotton became economically unattractive post-Independence, they shifted into a range of food crops, once again staking out a leadership position. As fertilizer subsidies were instated in the 1970s/80s farmers responded by taking up another unfamiliar but highly fertilizer-responsive crop: maize. The flexibility and agility of Nigerian dryland farmers contradicts the conventional image of smallholders as resistant to change, risk and innovation.

Simple survival and persistence qualifies as success when farmers are battered by shocks that would seem to be enough to ruin them. As described by Mortimore and Harris (2004), Senegalese farmers withstood the jolts of multiple government turnabouts on support to (and control of) groundnut production during the 1970s/80s. Droughts took their toll during the same period. Structural adjustment in 1984 and the CFA devaluation in 1994 delivered two more blows, increasing input costs. The cultivation of millet could not replace the gap left by groundnut because subsidized imports had fostered an urban preference for rice.

Farmers adapted each time despite severe hardships, although some migrated out. They learned how to reorient towards the local groundnut market, and improved their water and labor-use efficiency in millet and groundnut production by adopting new varieties and practices. They shifted emphasis to goat and sheep fattening when it became more profitable than crops. And they supplemented farm income with off-farm remittances. These achievements illustrate resilience, determination and skillful adaptation.

Also in Niger, the much larger Keita Valley Integrated Rural Development Project (1984-99; $65 million in cost) rehabilitated 20,000 ha of degraded lands through a wide range of interventions (Reij and Steeds 2003). Trees were planted, sand dunes were fixed, streambanks were stabilized, dams and wells were built, farmers were trained, credit was extended, schools were upgraded and health clinics established. The payoff will probably justify the high project cost over the long term, since its results increased incomes in the area by an estimated $6 million annually.

A major rice irrigation project known as the Office du Niger was reformed to correct the top-down, centralized approach that had previously failed (Reij and Steeds 2003). The reforms instituted in 1986 decentralized management of the irrigation works and liberalized the milling and marketing of rice (Gabre-Madhin and Haggblade 2001). Freed to benefit from their own labors, farmers responded by increasing yields more than threefold (from 1.5 to 5.5 t/ha) and tripling total production. The project generated an annual rate of return of 30% and farmers experienced a net revenue increase from $450 to $1000 per hectare. They are investing in expanding the project area.

Small-scale irrigation systems (shallow tube wells and gasoline pumps) triggered a widespread intensification of valley bottom (fadama) cultivation across Kano and Sokoto States of northern Nigeria (Reij and Steeds 2003; World Bank 1995). Adoption grew to 70% by 1994 from a baseline of 5% a decade earlier. The irrigated cultivation of high-value vegetables became the major source of income for one-third of the farmers. The return on the project investment was over 40%. A similar project in the Koumadougou Valley in eastern Niger was also successful (IFAD 1999).

Forest resource management improvement in Tanzania (1992-99) covered a range of interventions, including the strengthening of national institutions as well as policy and technology enhancements (Reij and Steeds 2003). The approach decentralized forest care to local communities (Wily and Dewees 2001). Management and protection of these woodlands improved remarkably. Private nurseries were fostered and produce enough seedlings for 3,500 ha annually. Improved stoves reducing family firewood requirement by 50% were saving 9,600 tons of wood each year. These two benefits alone generate a 12% annual return on investment for the overall project.

Community woodlots encouraged in Tigray, Ethiopia since 1991 have had dramatic impact (Reij and Steeds 2003). Eucalyptus trees were planted and cared for by local village groupings (tabias). A typical tabia manages about 70 hectares of woodlot, supporting wood worth about $90,000. An ex-ante impact analysis foresees the annual economic rate of return to eucalyptus planting of approximately 20% (Jagger and Pender 2003). Tree planting, bunding and terracing are helping to stabilize over 50,000 hectares of hillsides near Tegray, Ethiopia; more than 80 small-scale tree nursery enterprises have emerged, producing seven million saplings per year.

Rehabilitation of severely degraded rangelands in eastern Morocco during the 1990s was achieved by establishing clan-based cooperatives that encompassed 8,250 herders over a 3 million ha area (El Harizi 1998; Reij and Steeds 2003). They were provided with 30 kg of barley per year as compensation for setting aside 450,000 ha for recuperation for two years. The set-aside vegetation quickly recovered and its productivity jumped from 150 to 800 kg/ha of dry matter per year, a gain worth 50% more than the cost of the set-aside. Controlled rotational grazing now generates enough benefits that the herders pay grazing fees to their cooperatives.

The Mashreq and Maghreb project (Haddad and Eltom 2002) linked the Mashreq (Jordan, Syria, Lebanon, and Iraq) and Maghreb (Morocco, Algeria, Tunisia, and Libya) countries to combat desertification. Promising technologies were identified, but partners soon realized that policies and institutions also needed to be supportive for their implementation. The project catalyzed the creation of community-based organizations to develop 'negotiated action plans' that set standards for land management in their domains. They also function as communication and advocacy channels to promote policy and institutional reforms affecting property rights, land and water management, marketing, and credit.

Two projects covering eight African countries during 1997-2001 investigated whether the sharing of innovations developed by farmers themselves could trigger additional successes. The project cost was low, ranging from $20,000-$60,000 per country per year excluding external technical support. Approximately 50% of farmers exposed to their neighbor's innovations tried at least some of them on their own farms (Reij and Steeds 2003). Research and development staff initially expressed discomfort with the model, but became enthusiastic proponents as they saw the effectiveness of farmer-to-farmer sharing (IFAD 2002; Nasr et al. 2001).

Improved dryland crop varieties are an important set of success stories. The drylands are especially difficult to breed for, since they do not have the favorable conditions of moisture and fertile soils that were fundamental to the success of the 'Green Revolution' in more favorable zones. Dryland breeders have sought earlier-maturing types that avoid late-season drought; higher-yielding lines suitable for forage consumption as well as grain, given the importance of livestock in this zone; and built in resistances to pests and diseases that plague these areas.

Durum wheat is a dietary staple in dryland West Asia and North Africa. This is the zone of origin of this crop species, yet steadily increasing populations and shortages of arable land caused Syria to fall 28% short of its needs in annual production by 1985-89. During 1990-97 the country made a concerted effort to increase production including favorable policies towards credit, mechanization and on-farm wellwater irrigation, and the adoption of new varieties. The extra grain produced was valued estimated US$348 million annually (Mazid et al. 2003).

Pigeonpea is an important food legume grown and consumed mainly in dryland India and southern/eastern Africa. Resistance against *Fusarium*, a fungal wilt disease revived pigeonpea cultivation in India in the 1980s/90s, raised yields by 57% and delivered $62 million in net benefits by 1996, reflecting a remarkable annual rate of return on the research investment of 65% (Bantilan and Joshi 1996). Other varieties with a shorter, bushlike plant type matured in half the time of traditional varieties. This enabled farmers in the very driest areas to fit it into their cropping cycles, and others in moister areas to plant it as a second crop within a single season, following sorghum, chickpea or wheat. The bush varieties were rapidly adopted beginning in 1986, covering an estimated 150,000 ha in central India a decade later. The new crop package increased yields by a whopping 93%, and a 30% increase in net farm incomes (Bantilan and Parthasarathy 1998). The cumulative return on the research investment is projected to reach $117 million by the year 2007 (Ryan 1998).

Maize is another noteworthy success story, although it is a borderline crop for the drylands because it requires a reliable moisture supply. However it is an important food across Africa and a good market opportunity for dryland farmers located along the transition zone to wetter areas. New maize varieties including hybrids have had major impact across Africa where fertilizer was available and affordable and rainfall was reasonably assured (Sanders et al. 1996). Breeding research is making significant advances in increasing the drought tolerance of maize, particularly by reducing the anthesis-silking interval so that more seeds are able to successfully pollinate despite drought stress (Bänziger et al. 2000). This will reduce the risk of maize cultivation in areas where moisture is limiting for the crop. These varieties are spreading widely today in drought-prone southern Africa.

Fan and Hazell (2000) analysed the returns on past investments in development in less-favored, marginal districts/provinces (mainly drylands) in India and China. The investment categories examined were research and development (limited to crop varietal improvement in the case of India), irrigation, roads, education, electricity, and rural telephones. Surprisingly, they found that returns on investment were greater in the marginal areas than in more favored (wetter, more fertile) environments. Both productivity enhancements and poverty alleviation were greater in the less-favored districts.

This counters the conventional wisdom that development investments geared at reducing poverty should preferentially go to favored areas. They suggest that such favored areas in India and China have already benefited from major investments, making additional gains harder to come by (noting that this may not be extrapolable to Africa, where such gains may still await). The relative neglect of unfavored areas in the past has left under-exploited opportunities that are now being reflected in rapid growth. The benefits to poverty alleviation may be especially important, because otherwise the gap between rich (favored) and poor (unfavored) areas would widen further.

## Conclusions

Success stories across dryland countries and enterprises demonstrate that these areas are not the hopeless basket cases that media images often present. A world used to the continuing refrain of calamity in the drylands should take heart from the quieter, but no less significant progress that is being made.

This is not to suggest that the challenges are not formidable, nor that these ingenious and adaptable people can meet them without help. Unprecedented population growth, persistent poverty, looming climate change, and globalization add to the ever-present risks of drought and degradation of fragile dryland environments. They will need help to succeed in the face of these mounting difficulties. But it *does* suggest that research and development investments will pay off if they are properly planned and targeted with the needs and priorities of users in mind, and may indeed deliver larger benefits than are commonly expected.

This review of issues and experiences points strongly towards the need to break with past traditions of top-down development. Local practices and priorities for sustainable development should be studied and built upon, seeking and exploiting synergies with modern science. Users should be as directly engaged as possible throughout the process, through creative forms of participation and knowledge-sharing for impact. Rather than reductionist approaches and magic bullet solutions, a holistic, integrated ecosystems approach is essential.

Six areas that fit these criteria emerge as high priorities for development-oriented research:

1. Increase understanding of the nature, extent and severity of desertification, drought and dryland degradation through the combination of new technology with local priorities and values through user participation and ground-truthing;
2. The study of institutions and policies, both formal and informal and across levels (international, national, local) that constrain or foster sustainable dryland development, in search of lessons and win-win-win (growth/equity/sustainability) solutions;
3. Increase understanding of the functioning of dryland agricultural and natural ecosystems and the degree to which carrying capacity can be sustainably enhanced through increased soil fertility, improved water management, integrated crop-tree-livestock systems, and other innovations;
4. Participatory crop, tree and livestock selection and breeding to improve adaptation, stress tolerance, product quality and other valuable traits;
5. Build on dryland traditions of diversification to develop additional income-enhancing agricultural options such as new and domesticated indigenous crop/tree species, farming systems, products, markets (export as well as local) and supporting enterprises; and
6. Improve understanding of, and modalities for the exchange of information, knowledge, expertise, tools, and solutions in ways that engage the poor and address their needs.

To conclude, a basic dilemma faces dryland development: actions that provide food, shelter and income to people in need, threaten to degrade the very lands that underpin their livelihoods. Some believe that land degradation is an unfortunate but necessary byproduct of growth. Yet such degradation clearly leads to a dead end at some point. The challenge is to find ways to break this negative tradeoff—ways that simultaneously build livelihoods *and* save lands.

It will not be easy. However, experiences and opportunities suggest that if international, national, and local communities join hands and invest in the future by integrating their complementary skills and capacities, this dilemma can be overcome.

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