Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change

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Abstract

The world’s drylands will face not only increasing temperatures with climate change but more importantly also disruptions to their hydrological cycles resulting in less and more erratic rainfall that will exacerbate the already critical state of water scarcity and conflicts over water allocation.

The rural poor in dry areas will suffer the most from these changes and will require a range of coping strategies to help them adapt to changing climates. Strategies will include changing of cropping systems and patterns, switching from cereal-based systems to cereal–legumes and diversifying production systems into higher value and greater water use efficient options. The latter include judicious use of water using supplementary irrigation systems, more efficient irrigation practices and the adaptation and adoption of existing and new water harvesting technologies. Scope for the application of conservation agriculture in dry areas is thought to be limited by low biomass production but current evidence suggests that even small amounts of residue retention can significantly decrease soil erosion losses. These options will be supplemented by the development of more drought and heat tolerant germplasm using traditional and participatory plant breeding methodologies and better predictions of extreme climatic events.

The majority of drylands are occupied by rangelands with some 828 Mha in West Asia and North Africa alone. These vast areas provide environmental services such as the regulation of water quantity and quality, biodiversity and carbon sequestration. Rangelands have been neglected in the past partly because of problems of ownership, access and governmental policies that discourage investments in rangelands. The idea of payment for environmental services in rangelands is in its infancy but is discussed here as a potential option for better use and management of rangelands and as a safety net to reduce the vulnerability of rangeland inhabitants to climate change.

In addition to the promising technological options to reduce vulnerability to climate change a brief discussion is included on the institutional and policy options needed to create a better enabling environment for increased adaptation and ecosystem resilience.

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1. Introduction

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change leaves no doubt that the Earth’s climate is changing (Christensen et al., 2007). The last 60 years were the warmest in at least the last 1000 years, patterns of precipitation are changing with greater incidences of both floods and droughts. Mediterranean Africa is likely to experience as much as a 20% drying by the end of the 21st century with hotter summer temperatures and decreased precipitation and increased likelihood of summer droughts. Even though the global climate models are less reliable for Central Asia the region is likely to experience greater than average warming and decreased precipitation (Christensen et al., 2007). The AR4 concludes that the observed changes cannot be explained by natural phenomena and that there is now clear evidence of human influence.

For the drylands of Central and West Asia and North Africa (CWANA) it is not the effects of increased temperatures per se that are of major concern but rather the expected changes in precipitation, storm events, snow
fall and snowmelt, evapotranspiration, run-off and soil moisture, that will disturb the hydrological cycles. These cycles are already stressed in the region by excessive water withdrawals (90% for agriculture). The WANA region has the world’s lowest rates of renewable water resources per capita, e.g., less than 150 m$^3$ yr$^{-1}$ capita$^{-1}$ in Jordan (World Water Council, 2002), and suffers from associated environmental degradation and social problems.

These are some of the most dramatic and negative changes in climate predicted for any part of the world. Such areas will become affected by more frequent droughts, increased evapotranspiration, changes in rainfall patterns and associated wind erosion, increased salinization and decreased carbon mineralization. Ironically, an increase in heavy precipitation events is expected with a decline in the evenness of rainfall distribution adding to the risk of both flooding and drought for the main crops in these areas. Crop yields in the arid and semi-arid regions of Northern Africa, Southern Europe and the Middle East are expected to decrease by as much as 10–30% by the 2080 (IPCC, 2001).

As the WANA region is already the major grain-importing region of the world and because of the predicted negative affects of climate changes on agricultural production, there is likely to be a worsening of regional food security and negative affects on achieving the Millennium Development Goals of reducing hunger, poverty and environmental sustainability. Climate change is likely to add to the existing threats to food production and security from a number of converging trends such as high population growth rates, water scarcity, and land degradation. There is therefore an urgent need to increase the resilience of the production systems to these pressures via technical, institutional and policy options.

When vulnerability is defined as the degree to which production and livelihood systems are susceptible to, or unable to cope with, adverse effects of climate change, including climate variability, and extremes (IPCC, 2001), it is evident that the rural poor will be the most vulnerable to these changes both in terms of risk to their production systems and infrastructures (e.g., houses and roads) because they have less assets to call upon in order to cope with extreme events such as prolonged droughts, intense storms and subsequent flooding. The rural poor are dependent on the quality and functioning of the agro-ecosystems that they inhabit and they are particularly dependent on the natural resource base for their livelihoods through the provision of goods and services such as food, water, fodder, wood and other construction materials and fuel. Climate change will disrupt many ecosystem functions, altering their capacity to provide these goods and services and rendering them more susceptible to degradation.

Attempts to help the rural poor adapt to climate change must build on existing ‘coping strategies’ that generally involve three elements: preparing for harsh climates by developing various types of insurances, actually coping with the stress when it happens and thirdly, adapting and recovering from the stress (Dietz and Verhagen, 2004).

This article reviews some promising technological options that can improve ecosystem resilience to climate change and increase the adaptive capacities of land users, i.e. their ability to sustain the flow of diverse products and services that they depend on and to do so under constantly changing conditions (Sayer and Campbell, 2003). In addition the necessary accompanying institutional and policy changes required to enable the adoption and adaptation of these technologies are briefly discussed. These examples are illustrative of recent advances in dry areas rather than a comprehensive discussion of all of the possibilities.

2. Promising technological interventions to reduce vulnerability to climate change in CWANA

The range of technological interventions that can contribute to reducing the vulnerability to climate change by simultaneously preventing and reversing land degradation and sequestering carbon in drylands (mitigation) include; maintaining vegetative cover, grazing management, water management and salinity control, mulching and residue management, soil fertility management and crop rotations, improved fallows, shrub, halophyte and forestry plantations (Lal, 2001, 2002, 2003b). Below we discuss some recent developments in some of these interventions that can help farmers cope with and adapt to climate change in the CWANA region.

3. Improving water use efficiency

For dry areas it is clear that water, not land, limits agricultural production and that improving water use efficiency and decreasing demand must be major factors in the coping and adaptive strategies for climate change. This means a need to maximize water productivity in drylands rather than focusing on traditional approaches to maximize land productivity, develop additional sources of water where possible, and improve the utilization and management of all sources of water including low quality brackish, drainage and treated sewage water.

The adoption of supplementary irrigation, i.e., the addition of a limited amount of water to otherwise rainfed crops during water stress periods and critical plant growth stages, has been shown to increase the water productivity (kg biomass or kg grain m$^{-3}$ water) of wheat (Tritium spp.), barley (Hordeum vulgare), lentils (Lens culinaris), chickpeas (Cicer arietinum) and faba bean (Vicia faba) under dryland conditions where water is available (Oweis and Hachum, 2003). Table 1 shows a typical result obtained with supplemental irrigation.

There is also a revival in the documentation and dissemination of indigenous water harvesting practices, some originating from ancient times, which concentrate
scarcely rain water from a larger unproductive area to a smaller area where commercially viable crops, shrubs and trees can be grown under normally prohibitive amounts of annual rainfall. For example almonds (Prunus dulcis) and olive trees (Olea europaea) are being grown in Jordan and Syria in environments that receive only 120–150 mm rainfall annually. In Morocco and Tunisia trees and shrubs are being grown with 100–200 mm annual rainfall when combined with the use of contour ridges (Oweis et al., 2001, 2004).

Additionally, the efficiency of irrigated systems using high and low quality water can be greatly improved by introducing practices such as sprinkler and drip irrigation, laser levelling and reducing conveyance losses (Oweis and Hachum, 2003; Pereira et al., 2002). Options are available for the use of saline–sodic soils and waters via vegetative remediation with tolerant plant species and reusing drainage waters for irrigation (Qadir and Oster, 2004).

In Central Asia where 95% of water withdrawal is used for agriculture, simple practices such as changing from wasteful surface furrow irrigation to alternate furrow irrigation has resulted in water savings of up to 30% and yield increases of 15–20% in Kazakhstan. The introduction of plastic chutes in Uzbekistan has increased water productivity by 50–100% in farmers’ fields (ICARDA, 2005). Micro-furrow irrigation technology increased soil moisture from 0.7 to 0.85 of field capacity and reduced surface runoff from 5–50% to 2–20% in field experiments in Tajikistan.

Water harvesting can play an important role in the rehabilitation of degraded rangelands through practices such as the use of earth or stone dikes as micro-catchments on sloping lands to stimulate plant growth and prevent floods (Oweis et al., 2001).

### 4. Modelling water use efficiency

On farm water use efficiency (defined as the ratio of the required amount of water for a target production level to the actual amount of water used) has recently been shown to indicate that farmers in dry areas over-irrigate their crops by 20–60% (Shideed et al., 2005). A model has been derived from this work to assess the on-farm efficiency of water use based on six case studies in four countries (Egypt, Iraq, Jordan and Syria). The model is based on fixing an amount of water available and determining how this water should be allocated based on agronomic and economic factors of crop production. The model determines the inefficiencies of water use and is a useful tool for farmers and policy makers. Land allocation, crop choice, irrigation technology and output prices were found to be the main factors in the decision making of farmers growing multiple crops. The results suggest that only high increases in water charges can reduce the amount of water used for irrigation in the examples studied. These types of integrative models are examples of how complex natural resource management issues are being addressed. Models such as this will aid decision making on the type and area of crops grown and how best to allocate a given amount of water both on-farm and at greater landscape scales. All of these decisions will be affected by climate change and models can help increase preparedness and improve water use policies particularly with respect to reducing water demand.

### 5. Conservation agriculture

Conservation agriculture (CA) loosely defined as agriculture that maintains and improves crop yields and resilience against drought while protecting and stimulating the biological functioning of the soil (FAO, 2002; Dumanski et al., 2006), has been successfully applied in many parts of the world and is proposed as a practice for carbon sequestration in soils (Lal, 2002). However it has not been widely adopted to date in the dry areas where water limits the production of sufficient biomass to maintain a permanent soil cover and for significant amounts of crop residues. Stewart and Koohafkan (2004) suggested that small amounts of crop residues can reduce wind erosion considerably and increase soil water storage. Even these small reductions in soil loss under arid conditions are significant in terms of the retention of scarce soil nutrients where the soil remains bare for most part of the year (Zöbisch, 1998). Hence efforts to utilize CA in dry areas are being pursued.

In Morocco and many other dryland countries land degradation is occurring via inappropriate tillage practices, straw exportation and over-grazing. The farming systems in drylands are mainly integrated crop–livestock systems and so the solutions must consider the complexities of these
mixed systems. Pioneering studies in Morocco over the last 20 years or so have indicated that CA can function in areas with as little as 270–358 mm rainfall (Mrabet et al., 2003). Herbicide sprayed fallows conserved 55% more water in a 1.2 m soil profile compared with a conventional clean fallow (Bouzza, 1990). Wheat yields have improved without tillage and seed-bed preparation and soil organic carbon in the 0–25 cm layer increased by 5.62 t after 4 years and by 7.21 t after 11 years under no-tillage compared with no change under conventional tillage (Bessam and Mrabet, 2003). In the 0–20 cm soil layers the total increase in soil organic carbon was 3.4 t ha\(^{-1}\) in no-tillage compared with conventional tillage (Mrabet et al., 2001). These increases were reported to be proportional to the increases in crop residue cover. Associated with increased soil organic carbon in the surface layers is better soil fertility in terms of nitrogen, extractable phosphorus and exchangeable potassium and soil structure in terms of aggregate stability (Mrabet et al., 2003). Results of 6-year continuous trials of barley and barley-vetch \((Vicia sativa)\) in the drylands in Syria however, did not show any significant benefits of zero tillage with retention of stubble and straw on the soil moisture regime in an area receiving around 330 mm rainfall (Pala et al., 2000).

In Central Asia three main climatic zones are prevalent. Northern Kazakhstan has steppes with cold continental climates of long cold winters and short dry, hot summers. Here soils and climate are similar to the Canadian prairies small grain crops (spring wheat and barley) dominate the farming systems. (Suleimenov and Akshakov, 2004). The southern areas of Central Asia including Uzbekistan, Tajikistan and Turkmenistan are northern dry subtropics with cool winters and dry hot summers, Here cotton \((Gossypium spp)\) dominated with alfalfa \((Medicago sativa)\) rotations but has gradually been replaced by winter wheat. A third region straddles the first two and covers Kyrgyzstan and Southern Kazakhstan, similar to the southern region but with lower temperatures. These regions have good potential for the introduction of CA but only Kazakhstan has a short history (since the 1960s) of adopting conservation agriculture. Since the collapse of the Soviet system farmers in Kazakhstan have begun to diversify their cropping systems and land use management. Direct seed drilling is developing with locally manufactured machinery. Tillage that was previously done to control weeds is now being replaced by chemical control. Benefits from this change of practice include, a 3-fold reduction in fuel, greater productivity and soil and water conservation. Stubble helps retain snowfall and hence increases water storage. Limitations to wider adoption of conservation agriculture include a lack of suitable machinery, low quality seeds, inadequate weed control and poor seed placement. Only small areas are currently utilizing the conservation practices and there remain great challenges to wider adoption. The future success of conservation agriculture in the region will depend on a thriving agricultural business sector that can supply the necessary inputs at affordable prices and establish efficient markets. Issues of land rights and collective versus private farms are major factors in the spread of conservation technologies throughout the vast areas where potential for CA exists.

Different conservation tillage practices have been studied at 8 sites in the 5 Central Asian countries (Uzbekistan, Turkmenistan, Kazakhstan, Kyrgyzstan and Tajikistan) depending on the predominating cropping system and soil type (ICARDA, 2005). Tillage methods were studied separately for:

- fall tillage for rainfed spring wheat in N. Kazakhstan;
- for rainfed winter wheat in SE Kazakhstan, Kyrgyzstan and Uzbekistan;
- irrigated winter wheat in Uzbekistan, Tajikistan and Turkmenistan.

In rainfed spring wheat systems of Northern Kazakhstan minimum tillage was more profitable and energy saving and yields were greater than deep or reduced tillage provided nitrogen was applied (Table 2). Minimum-tillage combined with direct seeding of spring wheat is currently used on around 100,000 ha.

In rainfed winter wheat production systems in Southern Kazakhstan conservation tillage had little or no effect on crop yield but was more economical (Table 3). In Kyrgyzstan and Uzbekistan this practice has been shown to result in better moisture accumulation.

Yields of cotton can be improved in new double cropping rotations of cotton after wheat when minimum and zero tillage practices are applied compared with traditional ploughing with each crop (Table 4). These results show that conservation tillage practices are profitable in terms of energy and conservation of soil especially when combined with better fertilizer management and that yields are either not affected or slightly increased. Yields can be expected to increase over the longer term as soil organic matter is maintained or accumulated thus reversing the observed trends of decreasing yields with loss of soil organic matter.

There is a need to develop new crop rotations that include legume and oil seed crops in order to diversify the production systems from the existing unsustainable monocropping and to increase income-generating options for farmers in Central Asia. Current efforts include trials with field peas \((Pisum sativum)\), faba beans, sunflower

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Spring wheat grain yield (t ha(^{-1})) as affected by soil tillage and fertilizer in northern Kazakhstan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil tillage</td>
<td>Fertilizer (kg ha(^{-1}))</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Deep</td>
<td>2.04</td>
</tr>
<tr>
<td>Reduced</td>
<td>2.27</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.11</td>
</tr>
<tr>
<td>Average</td>
<td>2.14</td>
</tr>
</tbody>
</table>

Planted after fallow (2000–2002), LSD0.5 = 0.11 t ha\(^{-1}\).
tolerance (drought and extreme temperatures) is widespread

6. Participatory plant breeding

Traditional plant breeding research on abiotic stress tolerance (drought and extreme temperatures) is widespread but has been of greatest benefit to farmers in high potential areas or for those with enough assets to be able to modify their field conditions for modern crop varieties. Novel approaches are being tested whereby breeding for drought resistance is based on direct selection in the target environment, i.e., selecting for specific adaptations and involving the participation of farmers to overcome some problems with fitting crops to the wide range of target environments and users’ preferences (Ceccarelli et al., 2004). This methodology, termed participatory plant breeding, is cost effective, saves time and allows for a greater range of adaptation compared with traditional breeding programs. It is considered to be more appropriate and successful for marginal environments and socio-economic conditions than traditional breeding approaches (Mangione et al., 2006; Ceccarelli and Grando, 2007). Such approaches are needed to provide the necessary variability for the expected increases in climate extremes and to facilitate an increased awareness and understanding of the range of genetic variability in dryland plants.

7. Changes in cropping patterns

Over the short-term (up to 10 years) efforts should be concentrated on helping the poor cope with and adapt to climate change rather than placing efforts on predicting in greater detail the effects of climate change on agriculture or on efforts to mitigate emissions of greenhouse gases from agriculture. Farmers already adapt to climate change by changing their cropping patterns and rotations through earlier sowing, using shorter duration crops, and switching to crops that are more tolerant to heat, salinity and drought. These adaptations can also have a mitigating effect by sequestering carbon in soils as noted below.

8. Carbon sequestration and increased resilience of soils

The WANA region alone is vast covering some 1.7 billion ha and although the amount of biomass per unit area is lower than other wetter agro-ecosystems the amounts of C that are contained in the soil are significant on a global basis (Lal, 2000, 2002). Rangelands for example cover 828 Mha in

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Crop</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>No fertilizer</td>
<td>Wheat</td>
<td></td>
</tr>
<tr>
<td>Ploughing</td>
<td>1.61</td>
<td>0.79</td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>1.54</td>
<td>0.74</td>
</tr>
<tr>
<td>No tillage</td>
<td>1.60</td>
<td>0.74</td>
</tr>
<tr>
<td>Average</td>
<td>1.58</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Table 4 Cotton yield (t ha$^{-1}$) as affected by soil tillage in Yavan, Tajikistan in 2002

<table>
<thead>
<tr>
<th>Fertilizer kg N ha$^{-1}$</th>
<th>Wheat/cotton</th>
<th>Plough/Plough</th>
<th>Zero/Plough</th>
<th>Plough/Minimum</th>
<th>Zero/Minimum</th>
<th>Plough/Plough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plough/Plough</td>
<td>1.06</td>
<td>3.14</td>
<td>2.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero/Plough</td>
<td>3.22</td>
<td>3.42</td>
<td></td>
<td></td>
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<tr>
<td>LSD$_{05}$ = 0.18 t ha$^{-1}$</td>
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(Helianthus annuus), safflower (Carthamus tinctorius) and maize (Zea mays). Refinement of tillage operations can result in greater efficiencies and involve different timings of tillage operations with fall and early spring seedbed options suited to the particular crop mix and a reduction in summer fallows. Research is required on greater crop–livestock integration in these emerging systems in Central Asia.

Stewart and Koohafkan (2004) point out that no dramatic increases in production and soil fertility can be expected in the short term in dry areas, and farmers are unlikely to commit themselves to long-term solutions without adequate incentives. This argues for establishment of policies that will promote better soil and water management under conservation agriculture farming systems.

The identification of innovator farmers is an important part of any attempts to introduce new practices as it is much easier to build on these experiences than introduce completely new interventions in high-risk areas such as drylands. ICARDA is following the experience of one farmer in Kazakhstan for example, that has successfully converted 28,000 ha to conservation agriculture with no summer fallow (Suleimenov and Akshakov, 2004).

There is a clear potential for CA in dry areas but given the other limitations mentioned above, a more integrated approach is necessary that includes incentives, involves a multi-sectoral approach and, a more favourable policy environment. Additional information is required on where and with what type of farmers are the CA technologies likely to be feasible.
WANA with another 260 Mha in Central Asia (Lal, 2002). For this reason it has been suggested that drylands may have the greatest potential to sequester carbon (Scurlock and Hall, 1998). Lal (2002) estimated that soils of WANA have lost 6–12 Pg C over time but the sink capacity of these soils could be 3–7 Pg C or 0.2–0.4 Pg C yr\(^{-1}\) through remedial interventions to control or reverse desertification.

The soil carbon pool composed of soil organic and inorganic carbon is not only critical for the soil productivity and environmental functions, but also plays an important role in the global carbon cycle. Efforts to mitigate the detrimental effects of climate change include assessing the potential of different agro-ecosystems to sequester carbon either in plant biomass or in soils. Estimations of the potential amounts of carbon that can be sequestered in soils under different crop and soil and water management practices often fail to discount the C costs associated with the manufacture, transport, and application of fertilizers and energy costs associated with pumping irrigation water. For drylands there are the potential “hidden” costs of irrigation to consider if the water is drawn from groundwater and subsurface levels where the partial pressure of CO\(_2\) is much higher than that of the atmosphere and hence is associated with the release of large amounts of carbon into the atmosphere via equilibrium reactions (Schlesinger, 2000). Additionally, as many groundwaters in drylands have high dissolved calcium contents, the use of these waters for irrigation can result in precipitation of calcite and the release of CO\(_2\) into the atmosphere in amounts that can negate the beneficial effects of increased plant production and soil organic matter accumulation.

Soils of the dry areas have high calcium carbonate contents and can contain two to five times as much inorganic carbon as organic carbon (Lal, 2003a). When gypsum or organic material is added to dryland soils there may be leaching of calcium bicarbonate which is a type of carbon sequestration. However the role of inorganic soil carbon in carbon sequestration is little understood but has been estimated to be as much as 1 Mg ha\(^{-1}\) yr\(^{-1}\).

On the positive side legume-based cropping systems that are gradually replacing cereal–fallow systems in drylands, generally have reduced carbon and nitrogen losses compared with conventional nitrogen-fertilized systems (Drinkwater et al., 1998; Jenkinson et al., 1999). Additional emissions of nitrous oxides from legumes are likely to be small in dry aerobic environments (Sprent, 1987).

Whether or not soils act as sinks or sources of carbon depends on the balance of carbon input from primary productivity and carbon output from respiration of plants and soil organisms plus the possible “hidden” carbon costs mentioned above. This balance is influenced greatly by land management practices such as tillage, crop rotations, irrigation and fertilization. Therefore efforts directed at increasing the resilience of agroecosystems to climate change through crop, soil and water management practices (adaptation) may also contribute to mitigating measures such as carbon sequestration.

9. Institutional and policy options to reduce the vulnerability of the rural poor to climate change in CWANA

9.1. Crop insurances

To reduce the risk of crop failure from adverse weather governments have introduced help via debt forgiveness, livestock feed subsidies and crop insurance programs and have relied heavily on direct food aid and relief employment programs (Dietz et al., 2004a; Hazell, 2004). Hazell has argued that some of these have in fact worsened the situation. For example feed subsidies encourage over stocking and crop insurances encourage the cultivation of drought prone crops in high-risk areas (Hazell, 2004). Highly subsidized irrigation water tariffs encourage over-extraction of water resources at alarming rates. He suggests a need for new measures such as the development of rainfall insurance whereby insurance contracts are written in relation to local rainfall. This insurance works against some set amount of rainfall at a specific and perhaps critical time of the cropping season. If rainfall is below a set value then all who have purchased insurance receive payment. If there is no rainfall shortage nobody receives payment. Another option is better early warning drought forecasts to avoid committing resources before rainfall outcomes are known. Farmers, governments and relief agencies can profitably utilize these systems and avoid some of the perverse incentives associated with other risk management interventions.

9.2. Payments for environmental services (PES) in relation to climate change

There is increased interest in the concept of payment for environmental services as an option to increase the investments in dry areas subject to degradation and climate change (Adeel et al., 2007). These services include the regulation of water quantity and quality, conservation of biodiversity, erosion control and carbon sequestration.

The majority of the land area in CWANA is under range where rangeland productivity is limited by water, with rainfall often less than 200 mm. In addition large proportions of rangelands are estimated to be affected by land degradation but measurements of net ecosystem carbon dioxide exchange (NEE) have indicated that rangelands can act as C sinks (Saliendra et al., 2004). NEE varied from 151 to 659 g CO\(_2\) m\(^{-2}\) season\(^{-1}\) and was similar to values obtained from temperate rangelands. Lal (2002) estimated that soils of WANA can sequester 200–400 Tg C yr\(^{-1}\) or 20% of the global dryland ecosystems. Given this potential it is pertinent to consider who might pay land users to conserve and manage these vast rangelands that are generally common or state property. Clearly, there must be incentives and capacity to better manage the rangelands and investments in order to pay for the environmental services that managed rangelands can provide. In an analysis of potential
PES Dutilly-Diane et al. (2004) identified a number of beneficiaries of better rangeland management (Table 5). These included beneficiaries at the local, national and global scales.

As the benefits generated by rangelands are public goods, identification of the beneficiaries and who might pay for them is not an easy task. Recent interest in developing voluntary markets for carbon trading offers some promise although grasslands are not eligible under the Kyoto Clean Development Mechanism. Central Asia countries are eligible under Joint Implementation as economies in transition and the second window of the BioCarbon Fund will explore options for emission reductions and could include WANA countries (Dutilly-Diane et al., 2004).

Users of public lands such as tourists, water development agencies, energy generation companies and urban dwellers can be expected to have an interest in reducing runoff and wind erosion that result in siltation of reservoirs and massive dust storms and should be expected to pay for these services.

Interest is building in ‘bundling’ environmental services (Landell-Mills and Porras, 2002) whereby services may be combined for financing. Here there is potential to explore possible private-public linkages for financing.

Possible interventions to enhance environmental services revolve around the recuperation and regeneration of degraded rangelands such as efforts to introduce shrub plantations by governments utilizing drought and saline tolerant fodder plants, e.g., Atriplex spp. (Tiedeman and Johnson, 1992). Problems remain however on controlling access to, and use of these rangelands and the difficulties in implementing effective grazing management strategies (Dutilly-Diane et al., 2004). New institutional options are required for co-management of the rangeland resources. In addition, the practices described above under water use efficiency have a role to play in rangelands as well as on croplands.

Technical and management options for recuperating rangelands include the establishment of shrub plantations, use of water harvesting structures, controlled grazing and exclusion of areas from grazing. Much less is known and understood of the institutional and policy options required to implement these options. Unclear tenure arrangements often inhibit investments in the options as most rangelands are common pool resources or government controlled.

Ngaido et al. (2002) summarized three major approaches undertaken in rangelands in attempts to halt land degradation. The first is state appropriation of the land, revoking tribal or traditional control and attempts to organize cooperatives. The second is control by pastoral communities or organizations whereby the communities have some degree of control over access, use and management of the range. The third is tribal land titling to provide a legal basis for tribal property rights and control. To date these options have had limited impacts on rangeland degradation. PES programs need to carefully analyse the issues concerning property rights as they affect, access and use of rangelands.

### Table 5

<table>
<thead>
<tr>
<th>Scale</th>
<th>Environmental services supplied</th>
<th>Benefits</th>
<th>Beneficiaries / demanders</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global scale</td>
<td>Increased carbon sequestration</td>
<td>Mitigation of global climate change</td>
<td>International community / countries, private companies</td>
<td>Soil sampling, eddy flux towers, static chambers, vegetation cover by remote sensing</td>
</tr>
<tr>
<td></td>
<td>Enhanced plant and animal biodiversity</td>
<td>Enhanced resource base for future generation</td>
<td>Conservation groups, tourism industry, private companies</td>
<td>Survey of key eco-indicators</td>
</tr>
<tr>
<td></td>
<td>Dust storms reduction</td>
<td>Improved health, decreased maintenance costs in infrastructure and industry, decreased damages in agricultural production systems.</td>
<td>Tourism industry, urban populations, government</td>
<td>Remote sensing</td>
</tr>
<tr>
<td>National scale</td>
<td>Increased aquifer recharge</td>
<td>Increased water availability</td>
<td>Water users</td>
<td>Groundwater levels, groundwater use Stage heights at hydraulic structures, reservoir siltation, infrastructure damages</td>
</tr>
<tr>
<td></td>
<td>Flood reduction</td>
<td>Decreased damage of infrastructure (roads, reservoirs), crops and houses.</td>
<td>State (public infrastructure), utility companies, downstream population</td>
<td></td>
</tr>
<tr>
<td>Local scale</td>
<td>Increased water productivity</td>
<td>Conserve livestock productivity</td>
<td>Local herders</td>
<td>Biomass survey, soil sampling, stocking rate monitoring</td>
</tr>
<tr>
<td></td>
<td>Decrease of soil degradation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase of plant biomass</td>
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There is a consensus that whatever the land tenure arrangement, collective action and co-management are likely to play a key role in any efforts to manage rangelands and to organize payments for environmental services with particular attention required on (1), managing the relationship of the land managers or service providers with the purchasers and (2), managing the resource use and investment by members of the collective groups.

10. Conclusion

A range of technological options is available to help farmers cope and adapt to climate change. Some of these will also have a mitigating effect by reducing greenhouse gas emissions and/or sequestering carbon in biomass and soils. Continuing research efforts should focus on how the application of these options can improve the adaptive capacities of farmers, increasing their ability to cope with climate change and reducing their vulnerability to adverse effects. Adaptive capacity relies on access to resources, information and technology. Skill and knowledge to use resources and information are required suggesting a need to focus on capacity building and communication. In addition to these, other important factors include the stability and effectiveness of cultural, economic, social and governance institutions that can facilitate or constrain how farmers respond to climate change.

It has become imperative in rural development that interventions must build on the various coping strategies that the rural poor already have in terms of adapting to the harsh environments of the dry areas and there is a need to increase the resilience of the ecosystems to extreme climate events. In addition to changes in crop management mentioned above, these coping strategies include diversification of production systems, trade, migration and less dependence on agriculture through greater off-farm income generating activities. Generally, the poor are dependent on a narrower range of options for their livelihoods than those better off and are hence more sensitive to climate change. Efforts to buffer these effects should be given highest priority as well as efforts to bring modern science and technology to produce predictive options. In the short-term greater food security gains could be obtained from better predictions of the increases and severity of extreme weather conditions.

As the impacts of climate change are context specific including factors such as geographic location, economic, social and cultural characteristics, individual, household and group or tribal influences as well as institutional and policy constraints, there will be a need for better diagnosis of a multi-sectoral, multi-disciplinary nature. Efforts will also be required to mainstream climate change into development and poverty reduction strategies. The adoption of approaches such as the Integrated Natural Resource Management developed by the CGIAR and others that foster the de-centralization of decision making on natural resources and that can address these complexities need to be disseminated widely (Harwood and Kassem, 2003; Campbell et al., 2005; Tyler, 2006).

Drawing on information from a workshop in West Africa (Dietz et al., 2004a,b) and considering the options available for dryland conditions, efforts are required to enhance the resilience of dryland agro-ecosystems to climate change in the following areas;

Technologies:

1. Development of germplasm adapted to drought and temperature extremes using traditional and participatory plant breeding methods.
2. Prospecting for new plant and animal options for adaptation to climate extremes including the exploitation of halophytes and under-utilized plants.
3. Enhancement of soil and water conservation (use of low cost structures, adapted germplasm) and adoption of conservation agriculture.
4. Reduction in the demand for water in agriculture by water saving technologies and less water-demanding production systems.
5. Better predictions of extreme events, early drought warning systems, better fitting of germplasm options to different climates and gene prospecting.
6. Identification of thresholds for agro-ecosystem functioning, e.g., rangeland vegetation, water quantities and quality, keystone species for ecosystem functioning.
7. Conservation of dryland biodiversity and diversification of production systems.
8. Better predictive models on adaptation and responses to drought at crop, production system and ecosystem or landscape levels.

Institutional and policy options:

1. Exploration of the linkages with private sector for energy generation and ecotourism in dry areas as an alternative and complementary livelihood strategy in marginal dry areas.
2. Training and capacity building in ecosystem resilience (not agriculture per se), risk management and coping thresholds.
3. Policy analyses to assess preparedness for climate change.
4. Analyses of livelihood strategies in relation to climate risk management including migration patterns, micro-credit options and cash flows and investments through remittances (off-farm income).
5. Strengthen social safety nets through insurance schemes and a better understanding of existing local networks.
6. Provision of high quality information that is accessible to land users in appropriate forms.
7. Greater integration of scientific disciplines on knowledge of climate change, variability, adaptation and mitigation.
8. Decentralization of decision-making and policy formulation and greater attention to land user-policy maker linkages.

References


Tyler, S., 2006. Co-management of Natural Resources: Local Learning for Poverty Reduction. IDRC, Ottawa, Canada.
