Sustainable Agriculture in Central Asia and the Caucasus

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Research Prospectus: A Vision for Sustainable Land Management Research in Central Asia

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Research Prospectus:

A Vision for Sustainable Land Management Research in Central Asia

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Abbreviations

ADB	Asian Development Bank
Asl	Above sea level
ARD	Agricultural Research for Development
ARP4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
ARI	Advanced Research Institute
AVRDC	The World Vegetable Center
CAC	Central Asia and the Caucasus
CACAARI	Central Asia and the Caucasus Association of Agricultural Research Institutions
CACILM	Central Asian Countries Initiative for Land Management
CATCN-PGR	Central Asian and Trans-Caucasian Network for Plant Genetic Resources
CCER	Consortium Commissioned External Review
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CIESIN	Center for International Earth Science Information Network
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)
CIP	Centro Internacional de la Papa (International Potato Center)
CP	Challenge Program
CSO	Civil Society Organization
CWANA	Central and Western Asia and North Africa
EM	Electromagnetic
FAO	Food and Agriculture Organization of the United Nations
FESLM	Framework for Evaluating Sustainable Land Management
FTI	Faculty Training Institute
FDEM	Frequency Domain Electromagnetic
GEF	Global Environmental Facility
GHG	Greenhouse gas
GIS/RS	Geographic Information System and Remote Sensing
GFAR	Global Forum for Agricultural Research
GLP	Good Laboratory Practice
GNI	Gross National Income
GPR	Ground penetrating radar
ICARDA	International Center for Agricultural Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
ICM	Integrated Crop Management
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICRAF	The International Centre for Research in Agroforestry
IIWG	Intercessional Intergovernmental Working Group
IFPRI	International Food Policy Research Institute

ILRI	International Livestock Research Institute
ICWC	Inter-State Commission for Water Coordination
IMPACT	International Model for Policy Analysis of Commodities and Trade
IPCC	Intergovernmental Panel for Climate Change
IPGRI	The International Plant Genetic Resources Institute
IPM	Integrated Pest Management
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IRRI	International Rice Research Institute
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
LFM	Link Farmers to Market
MAP	Medicinal and Aromatic Plants
MD	Minimum Data
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
Mha	Million hectares
MRWF	Medium Range Weather Forecast
MTP	Medium Term Plan
NARS	National Agricultural Research System
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NRM	Natural Resource Management
PFU	Program Facilitation Unit
PMI	Policies, Markets and Institutions
PGRFA	Plant Genetic Resources for Food and Agriculture
PSC	Program Steering Committee
PSR	Production System Research
RCT	Resource Conserving Technology
R&D	Research and Development
RNA	Research Needs Assessment
RS	Reflectance Spectroscopy
SLM	Sustainable Land Management
SLM-IS	Sustainable Land Management-Information Systems
SLM-CB	Sustainable Land Management – Capacity Building
SLM-KM	Sustainable Land Management – Knowledge Management
SLMR	Sustainable Land Management Research
SWEP	System-Wide Eco-regional Program
TAC	Technical Advisory Committee
TDEM	Time Domain Electromagnetic
ToT	Transfer of Technology

USDA	United States Department of Agriculture
UNCCD	The United Nations Convention to Combat Desertification
UNCED	The United Nations Conference on Environment and Development
UNDP	United Nations Development Program
UNEP-GEF	United Nations Environment Program-Global Environment Facility
UNESCO	United Nations Educational Scientific and Cultural Organization
UNCCC	United Nations Framework Convention on Climate Change
WUA	Water Users Association
WWF	World Wildlife Fund
ZEF	Zentrum für Entwicklungsforschung (Center for Development Research), University of Bonn, Germany

Content

List of Figures

List of Tables

Executive summary

Central Asia consists of five ‘transition’ economies (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) and covers 399.4 million hectares (Mha), about two-thirds of which are drylands. Developing sustainable land management options in this region must take into account the biophysical constraints (low rainfall, extreme rainfall variability, and heat and cold stresses), climate change effects above global average that may exacerbate those constraints, and couple this with the problems of sociopolitical and economic transition inherited from the former Soviet Union. Growing, predominantly rural, populations expect secure income options, wealth and stable and healthy food supply under changing environmental and socio-political conditions. Improving the productivity of drylands in Central Asia is therefore an urgent task for the nations and calls upon the national and international research communities to act.

Natural resources in the region have been degrading over the decades as a result of the heavy emphasis put by the Soviet system on production instead of production efficiency. After independence, the transition in agriculture from a central command system to market-driven mechanisms has often been painful. Farmers, who were employees of the former state-controlled collective farms and have now become private entrepreneurs, often lack knowledge, skills, and capital. They face dwindling and usually insufficient agricultural infrastructure, difficult access to markets (countries are land-locked, infrastructure is decaying and international borders constraining the flow of goods have been erected between the countries after independence), and, in some of the countries, strict government controls, inadequate institutions and often conflicting laws and policies. Water resources are being wasted in highly inefficient irrigation management systems; as a consequence, 40 to 60% of the land is highly salinized. Land is also often polluted with agro-chemicals as a legacy of former production systems; however, the effects of this seem to be diminishing as agrochemical use is much lower than it was in the past.

Drylands in Central Asia are predominantly used as rangelands for grazing cattle and goats. Forests cover 4%, and arable lands 8% (one-third of the arable lands are irrigated, the rest are rainfed). The major crops grown are cotton, wheat, maize, sunflower, potato and rice, often as mono-cultures on large areas. The climate is continental with cold winters and hot summers, the altitude ranges from 50 to 7500 m above sea level. Four major agro-ecological units are important to look at: (1) irrigated croplands, (2) rainfed croplands, (3) rangelands and (4) mountains. We argue for sustainable land management (SLM) options to be developed mainly for these four units, in order to achieve maximum impact with limited resources.

Central Asia has been experiencing global warming above the global average, and it is predicted that these trends continue, but with varying effects on patterns of rainfall in the region (higher rainfall in the North, but less rainfall throughout most of the South) and during the year’s seasons. Approaches to mitigation and adaptation must therefore consider the regional differences. Climate change may have positive bearings on the rainfed areas in northern Kazakhstan, where higher temperatures and more rainfall may increase wheat productivity. On the other hand, larger drought in the South is likely to mean a reduction in vegetation cover, which thus affects options for mitigation and carbon sequestration in vegetation and soils of the region. However, the exact size and direction of changes is not easy to gauge, as large-scale models of climate change have not been broken down to address regional and sub-regional variation. As glaciers retreat, less runoff water will be available on the long run, and land use in the irrigated areas has to be changed to more drought resistant crops, more effective irrigation approaches and, eventually, lead to complete system overhauls and changes to drip irrigation of cash crops instead of having large areas irrigated for cotton and cereals. This is costly, and also may meet resistance by national policies which today mostly emphasize achieving independence in national staple food production. Breeding efforts are needed to make current crops more resilient against drought, salinity, and increased pest incidences as regional topographic/climatic barriers against migrating pests break down.

With regard to rangelands, building up vegetation cover should provide more resilience against drought but may be hampered by higher temperatures and less rains than present. With regard to carbon sequestration, expectations are often exaggerated in the literature, and more research is needed. It may be best to try to harness synergistic effects, e.g. concentrate on regions where carbon sequestration can be coupled with effects on biodiversity conservation or other benefits, such as erosion control and watershed protection. Thus, emphasis of mitigation and adaptation should be put into preservation of a productive vegetation cover in mountain areas, and water-saving measures in the irrigated croplands where much of the food is grown.

All that is currently little substantiated by data. There is a need to develop better regional scenarios that study climate change effects on various aspects of cropping, cropping and rangeland systems, water and irrigation management and the socio-economic situation.

Modern conservation agriculture presents a very promising opportunity as a strategic platform for combating land degradation and for raising production in the region. Conservation agriculture will therefore be placed center stage of research on: (1) land use technologies and integrated practices (introduction of conservation agriculture on irrigated and rainfed, flat, and sloping lands, crop portfolio diversification, efficient on-farm rainwater and irrigation water management, and integrated water resources management at all levels); (2) crop rotations and diversification including genetic enhancement (breeding) for crop varieties that are more resistant to abiotic (heat, cold, drought, salinity) and biotic (pests, diseases) stresses; (3) the development of integrated tree–crop–livestock–rangeland management systems.

Resource conserving technologies, based on the basic tenets of conservation agriculture (i.e., minimum or no-till; maintenance, as far as possible, of year-round organic ground cover; diversified crop rotation) are likely to provide economic benefits to the farmers that may be large enough for a fast-track adoption of SLM measures. However, adaptive research is required to make this happen in the four major agro-ecological systems. SLM should contribute to economic growth, social equality, and help achieve a balance in the competing use of land for livelihoods and ecosystem stability. Technologies to achieve these goals are available, but need to be tested and adopted under the specific social–ecological–economic frameworks of the transition countries in Central Asia.

The successful introduction of CA will pave the way for the introduction of other measures to develop long-term sustainability of the natural resources. For the generation and transfer of technologies in a cost effective manner, we propose (1) the use of farmer participatory research approaches at several ‘benchmark’ sites representing the major production systems as outlined above; and (2) the development of a regional meta-database for the dynamic assessment of land degradation and rehabilitation prospects, for the proper handling of issues of trans-boundary uniformity of methodologies and data quality, and for similarity analyses as a basis for the out-scaling of successful approaches. The meta-database will form the basis for the successful out-scaling of the successful approaches at the benchmark sites to the wider region.

This focus on technologies will be seconded by research into the economic, institutional, social, and policy aspects of land, water, and natural resource use (cf. Figure 1). Economic research will focus on economic assessments of the proposed technologies including machinery and equipment, and on developing value chains and links from farmers to markets. Institutional research will address the needed flanking policy options.

Furthermore, we suggest to support the research program outlined here by (1) targeted infrastructural measures (building-up laboratory capacity in modern soil analysis, GIS and remote sensing, and weather forecast capacities) and (2) a strong focus on academic as well as technical capacity building, in order to enable the national research systems to take up the challenges by themselves, through development and refinement of appropriate machinery prototypes for conservation agriculture. Facilitating access of farmers to indigenously manufactured machinery will improve rates of adoption for new technologies.

This Research Prospectus outlines the bio-geophysical setting of Central Asia, identifies the problems and the drivers of dryland degradation, discusses the priorities for sustainable land management research (SLMR), and outlines the opportunities and approaches for enhancing the productivity and sustainability of the production systems in specific agro-ecologies.

This document puts emphasis on the innovations that address SLM issues to significantly improve total system productivity. It builds on past achievements of the Consultative Group on International Agricultural Research's (CGIAR's) Program for Central Asia and the Caucasus (CAC), as well as on various priority setting exercises repeatedly carried out with all relevant partners in the region, so as to specifically meet the needs and expectations of the regional national agricultural research systems (NARS). The Prospectus also links specific questions with objectives and provides an insight into the activities that must be taken to achieve the stated goals of the production systems spread over the specified agro-ecologies, namely irrigated and rainfed dry lands, range and pasture lands, and the sloping lands in the hills, steppes, and the mountainous regions. This Research Prospectus should also guide SLM research in the context of the Central Asian Countries Initiative for Land Management (CACILM) program, as it builds on the findings in the first phase of this program. Addressing SLM strategies this way will contribute to achieving the Millennium Development Goals 1 (eradicate extreme poverty and hunger), 7 (ensure environmental sustainability), and 8 (develop global partnerships for development), under the scenario of climate change above world-average.

1 Introduction: An overview of Central Asia

1. Land degradation and land use are inextricably linked to each other. This applies also to the rainfed and irrigated drylands of Central Asia. Any attempts at mitigating land degradation in this region will need to address land use and land use policies as the major entry points to more sustainable resource use.

2. In Soviet times, the Central Asian republics belonging to the USSR were interlinked within the centrally managed economic system of the Socialist bloc. Each of these republics specialized in producing a specific agricultural commodity – a component of the larger system – according to prevailing agro-climatic and biophysical resources. For instance, Uzbekistan specialized in producing cotton, while Kazakhstan was the breadbasket of the region. After their independence in 1991, the five republics in Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) were faced with a disruption of the earlier trade arrangements and economic linkages for production and distribution of farm products. With the collapse of these arrangements, all republics had to develop their own independent economies in which agriculture continues to play an important role for the local immediate food needs, for example wheat supply, while feeling the need to be more integrated into global markets.

3. Under the former Soviet agricultural production system, the large-scale collective and state farms controlled some 95% of agricultural land and produced the bulk of the commercially marketed output. Product markets and input supply channels were largely controlled by state organizations. Commercial production from state enterprises was supplemented by household plots that relied on part-time family labor and produced mainly for the subsistence needs of the family (as well as generating additional income through sales in the local markets). After independence, the production environments of the farming systems in Central Asia underwent major changes which have led to the breaking up of the large-sized ‘collective farms’ into small private farm holdings. This has required a shift in the research paradigm towards development of technologies and agricultural machines that are best suited for small farm households and production units.

4. Despite some signs of recovery in the last five years, the GNIs per capita for three countries of the region (Kyrgyzstan, Tajikistan and Uzbekistan) still range between US$ 390 and US$ 610 per year (World Bank 2008) A recent report from the World Bank reveals that some of the countries in Central Asia are facing development challenges similar to those seen by poor countries in Africa (World Bank 2005 & 2006). Income inequality between the agricultural and non-agricultural population is growing in most of the countries due to the low economic efficiency of agricultural production, small capital investments in agriculture – including agricultural research – and slow institutional and infrastructural development.

5. National economies are opening up to global agricultural trade, albeit to different degrees. Jump-starting into open markets may indeed prove to be counterproductive with regard to the livelihoods of the agricultural populations unless carefully designed to avoid distortions and inequalities. It is important to emphasize that attaining ambitious growth goals at all costs may adversely affect poverty reduction if inequality begins to accompany growth.

6. National and local governments in Central Asia are currently facing tough decisions with far-reaching economic and political consequences. There is an urgent need for shifts in paradigms and policies to enable the transition from extensive to resource-efficient agriculture based on sustainable agricultural practices. Therefore, research on, and dissemination of, economically more efficient farming practices is urgently needed to increase farmers' competitiveness and incomes, while at the same time increasing the long-term sustainability of agriculture in the region.

1.1 Structural reforms: the emerging private sector in Central Asia

7. Agrarian reforms launched in 1991 have tended to focus mainly on land reforms consisting of 'de-collectivization' of the large state-owned enterprises and privatization of holdings (Wehrheim and Martius 2008). The extent of privatization varies by country. Whereas land reforms are taking place in all the countries, to-date private land tenure has been granted only in Kazakhstan and Kyrgyzstan. A quite sizable part of the agricultural output is generated by household plots and these have offered an important safety net for households struggling to cope with the economic transition. Presently, almost all agricultural land is cultivated either by private farmers (Kazakhstan and Kyrgyzstan) or individual leasehold farmers (Turkmenistan, Tajikistan, and Uzbekistan). Nearly all livestock are now held by private herders in small herds. However, most of the livestock production by individual small herders, especially in remote areas of Central Asia, is more of a subsistence nature than a commercial enterprise.

1.2 Food security: a policy priority

8. With the collapse of trading systems and the lack of foreign exchange reserves, the governments of Central Asian countries gave high priority to domestic food security. Food self-sufficiency was often grounded on a national, independent production of wheat (e.g. Uzbekistan and Turkmenistan, which have become self-sufficient in wheat over a short period of time). The area sown to cereals has increased by 24% on a regional level since 1992. However, it should be highlighted that this regional average masks two important trends at national levels. First, there has been an exponential expansion of area under cereals in Uzbekistan and Turkmenistan, and second, in Kazakhstan, which was by far the largest

producer and still is the major exporter of cereals in the region, the area under cereals decreased from 25 Mha to 14 Mha over the last decade. Presently, of the 40% of the arable area of Central Asian countries that is sown to cereals, 80% is wheat. With the growing populations, it is likely that the demand for cereals will continue to increase in the region. Although wheat is the major cereal, the demand for rice is projected to grow faster. Increasing domestic production to meet these demands from limited land under irrigation will require investment in productivity, enhancing and resource saving technologies and, naturally, in agricultural research to develop these technologies.

2 Land use and agro-ecologies in Central Asia

9. The total geographic area of Central Asia comprises five land-locked republics (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) and covers about 399 million hectares (Mha). Pastures (rangelands) occupy 255 Mha, and agriculturally unused lands (urban areas, remote deserts, mountaintops, and glaciers) occupy 112 Mha, together 92% of the total geographic area. Arable cropped lands (32 Mha) occupy close to 8% of the total geographic area, and roughly 36% of these cropped lands are under irrigation (ADB 2007, World Bank 2008). Forests are sparse and not contained in the statistics above; they cover in total approximately 4% of the area. The region is very diverse in geography, climate, and natural resources. Rainfall is variable and uncertain, and the region is subject to periodic drought. Much of the area is subject to the extremes of cold winters and hot dry summers, which limit cropping options, particularly in the rainfed areas.

10. Broadly classified, the major agro-ecological regions for crop production in Central Asia include irrigated and rainfed cropland, and rangelands in deserts, steppes and mountains (Table 1, Figure 2). Mountain areas are categorized into zones based on their altitudes. Twelve different zones are recognized in Tajikistan. The altitude ranges from about 50 m asl (i.e., the Aral Sea) to 7500 m asl (i.e., the high mountain-tops of the Pamir and Tien-Shan ranges).

11. Based on the UNESCO classification for arid zones, twenty-one agro-climatic zones are found in Central Asia. Some 68% of the area is occupied by just two of these zones (sparsely vegetated deserts and grassland / shrubland), and another 30% encompasses 10 zones Figure 2, Table 2).

12. Central Asia has a continental climate with winter temperatures between -3 °C and 20 °C. In the mountains the temperatures can be as low as -45 °C (Rudenko et al. 2008; Ryan et al. 2004). Summer temperatures range from 20 to 40 °C, but can be as high as 50 °C in the Kyzylkum and Karakum deserts. Rainfed agriculture is generally practiced in areas with an annual precipitation of between 250 and 400 mm (Figure 3, Table 3). On land with less precipitation, irrigation is needed. Annual precipitation of more than 400 mm is received only in a narrow belt in the South-East (Figure 3). Precipitation is received mainly during the winter season. The length of the vegetation growing period (Figure 4) is constrained by rainfall, temperature, and soil moisture.

13. Land use and land cover follow the patterns of rainfall and of the length of the growing periods (Figure 5). Rainfed wheat is grown in the North (Kazakhstan), and irrigated agriculture practiced in the South-East. These two zones are separated by the grassland/steppe belt. This vegetation sequence represents an important gradient and transect studies would be adequate to identify regionally adapted solutions. Transects for research should therefore

capture the north–south rainfall gradient as well as the slope gradient in the mountains. Since human-induced land degradation is expected to be more prominent in the irrigated narrow belt in the South-East (Figure 6) eventually more than one transect might be needed to cover both aspects fully, and several countries would be involved.

14. At present, we envisage that four eco-regional areas should be the focus of the SLM research. These would include (1) irrigated croplands, (2) rainfed croplands, (3) rangelands, and (4) mountains. In all of these four areas, various cross-cutting issues (breeding and seed supply, crop and livestock management, socio-economics, institutional, and policy research) need to be implemented. These four eco-regions are described in the following sections.

2.1 Irrigated agriculture

15. Irrigated agriculture is dominated by the production of cotton and wheat, but many other crops are also grown. Roughly one-third of the irrigated cropland is occupied by small-holder farmers (dekhans in Uzbekistan; Djanibekov 2008). In Central Asia, the amount of irrigated land has been steadily expanded from 4.5 Mha in 1960 to 7.9 Mha today. In this period, the average probability of a farmer in a typical area (such as the Khorezm region in Uzbekistan) obtaining sufficient irrigation water declined by 16%. That is, a farmer has now a substantially higher risk of losing his crops due to insufficient water supply than 20 years ago. This is exacerbated by a strong year-to-year and regional (that is, higher risks at the tail end of the irrigation system) variation of water availability (Mueller 2006). Because of heavy irrigation, groundwater levels rise quickly every spring. This results in a capillary groundwater rise and so-called 'secondary salinization' of the soil (Akramkhanov 2005; Ibrakhimov 2005). Cotton yields have decreased due to worsening soil conditions. Salt leaching in the fall and spring seasons is considered a remedy for improving crop yields. However, when excessive leaching is practiced over a large area without a functional drainage system, it only partially reduces soil salinity and often worsens the problem (Mueller 2006; Forkutsa et al. in print). In addition, since independence, investments in the operation and maintenance of the irrigation system have been extremely slow, which has led to major water losses.

16. Rice, potato, vegetables, corn, and fodder/forage crops occupy a relatively small area in the irrigated lands compared with cotton and wheat. Highly remunerative irrigated rice-wheat systems are practiced in down-stream regions of the Amu Darya and Syr Darya river basins. Irrigated lands, generally located in the weakly developed alluvial soils (former river beds and deserts in the lowlands), are predominantly of sandy-loam texture, which favors nutrient losses and drastic losses in organic matter. Some 40 to 60% of the total irrigated area is moderately to highly saline, which adversely affects crop production (Ibrakhimov 2005 and several reports cited therein; cf. also Table 4).

17. Improved irrigation and drainage management – on-field and system-wide – is needed together with diversification of crops. Thus, for irrigated agriculture the challenge is to increase water productivity, improve and maintain soil fertility and diversifying the cotton-wheat rotations. In irrigated agriculture, soybean, common bean, mung bean, groundnut, maize, and vegetables can easily be included as second crops after a harvest of winter wheat. Elimination of short- and long fallows by introducing food and forage crops will prevent the land degradation which has been developing fast throughout the region. Several potential alternative crops, such as chickpea, lentil, buckwheat, and field peas, offer new options for increased incomes under rainfed condition. Several crops, such as sorghum, pearl millet, safflower, and rapeseed, known to be drought and salt tolerant, can be grown successfully in saline environments. Legumes, cereals, oilseeds, potato, and fodder crops and grasses provide options to reduce summer fallows in irrigated areas and potentially substitute uneconomic crops in the rainfed areas. Relay cropping of wheat into a standing cotton crop, a practice common in Uzbekistan, can potentially reduce winter fallows and also provide some green fodder (grazing of winter wheat) for the livestock. Also winter barley and triticale are good candidates for such cropping practices.

18. ICARDA and partners have carried out several projects on conservation agriculture which are briefly reported here. In irrigated areas, forms of reduced tillage such as minimum tillage instead of plowing showed to provide similar yields as deep tillage operations. They were also more economical, for example a net profit of US$ 399 was achieved in Tajikistan, almost double the US$ 239 achieved with conventional tillage. Furthermore, new equipment introduced for planting winter wheat into standing cotton resulted in a reduction by 20-25% of seed and nitrogen fertilizer application rates. The raised-bed system, which also was tested, reduced seed rates almost by half, and provided 22% and 48% higher wheat yields in Azerbaijan and Kazakhstan, respectively. In Azerbaijan, profitability per unit of productions costs was about 36% higher with raised beds than under traditional planting. In 2005, for example, at three farms, an average net profit US$ 520 was obtained from 1 ha of raised-bed planting, almost 30% higher than the US$ 404 obtained in the control plot.

19. Karakalpakstan, a drought-stricken region of Uzbekistan situated in the Aral Sea basin, is one of the textbook examples of land degradation. CA components have been tested here as a coping strategy under a FAO-funded project in which basic principles of conservation agriculture were demonstrated and conducted in the fields of cooperating farmers during 2004-2007. Crop yield is a very important factor for farmers to consider new innovations as attractive. During experiments, despite the fact that wheat stand counts were 8-10% lower in no-till plots after crop establishment, head counts at maturity were higher in no-till plots, providing on average 2.5 t ha^{-1} of wheat yield over two years.

20. Direct seeding of wheat thus resulted in the same yield as traditionally tilled fields, with 2.4 t/ha. Farmers could see that higher tillering had made up for lower stand counts so

that there was no yield penalty. Such simple experiments demonstrate clearly the benefits and are thus convincing enough for farmers to take up the new technology.

21. CA is a new system where all ingredients such as nitrogen application, weed control, crop rotation need to be studied. Some lessons learnt from in-depth studies are: Experiments with different nitrogen application rates and times indicate the importance of split application in March and April that provided 2.5 t ha^{-1} yield, versus 2.0 t ha^{-1} in a treatment with fall application. Manure application tended to increase wheat yields by 0.6-0.7 t ha^{-1} over the 1.6 t ha^{-1} achieved in the control. There is a yield penalty if no herbicide is applied to no-till plots to control weeds (as well as when application is untimely, or the wrong herbicide is applied). During the project duration plots without herbicide treatment had 0.7 t ha^{-1} lower yields than those treated with herbicides. Surface residue helped to maintain higher soil moisture content, but only about 3%.

22. Uniform land leveling is a prerequisite for introducing CA in irrigated lands, as it reduces water use. Laser-assisted land leveling in the project contributed to a 10% increase in wheat yields. Expenses in production costs using permanent beds were about 27% lower than with conventional practice. The main conclusions of the project were that no-till and raised-bed planting are suitable technologies for the local conditions south of the Aral Sea, provide similar or higher crop yields, and save resources including fuel, seeds, and labor, thus reducing farmers' costs.

23. The Sustainable Land Management Research project involves therefore activities in 5 countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan). In Kyrgyzstan, the performance of new cultivars (wheat/barley) under different tillage systems is evaluated. Three planting methods (direct drilling into stubble, raised bed planting, and traditional cultivation, which includes tillage and high seed rate planting) were compared with various selected cultivars. Cultivars grown on raised beds yielded higher than with other methods of planting. The local wheat variety Asyl performed well and was most suitable for bed planting.

24. In Turkmenistan, farmer trials were directed at adapting resource conserving technologies and validate them under field conditions. Direct drilling was compared to the farmer practices of growing wheat, in areas where cotton and wheat are cropped in rotation. The main emphasis was on evaluating the costs of production. Significant savings, up to 24% of input costs, were achieved by direct drilling of wheat into standing cotton.

25. Another study that looks at salinity management in the bed and furrow system was conducted in a salinity-affected area of Turkmenistan. The common practice in such areas is to leach soils before the planting season; if permanent beds are used, then leaching techniques need to be investigated. Water input for leaching can reach up to 5,000 m^3 per hectare, which is an enormous amount in those highly water-dependent areas. Strategies tested to reduce

water input included the omission of the pre-sowing irrigation, and the alternate irrigation of furrows. First results indicate that water saving of up to 1,600 m^3 can be achieved without pre-sowing irrigation in wheat cropping. Leaching in permanent beds is best achieved by continuously irrigating alternate furrows each irrigation cycle. Similar leaching techniques in permanent beds were studied in Uzbekistan. More studies are underway to repeat the trials in other locations to test the leaching strategies.

26. In Uzbekistan, studies with winter wheat on raised beds with and without residue yielded above 6 tons per hectare. Yields on raised beds with and without residue were, respectively, 14% and 7% higher than control plots planted according to the farmers' practice. Additional savings, accrued from reduced tillage operations and reduced seed rate, provided 10-12% more to farmer income, the result attained from the wheat cropping season only. In the cotton cropping season, besides raised-bed planting, some other potentially income-increasing options are under study, such as intercropping of mung bean with cotton. This work on crop diversification is important, as integrating promising varieties of oil and leguminous crops into the rotation would be fulfilling one of the tenets of the CA system. The traditional knowledge about cotton-alfalfa rotations, once widely practiced in the cotton-growing areas, can be utilized and reintegrated. Oil crops, on the other hand, are the source for local cooking oil production which could replace the current imports.

27. The final step is to conduct policy and institutional analyses that will allow for the development of 'enabling policy options' for sustainable land management in Central Asia. One first result of the ongoing Sustainable Land Management Research (SLMR) project is that the attitude of the land users towards their land is a major factor. Land users underwent the transitional processes of the recent years that were witnessed in all CAC countries, with land reform and ownership consolidation, but also bringing up new private farmers with often limited knowledge and skills. Those farmers that survived this process are concerned about stable crop production, and their incomes. The recurring and increasing water shortages in Central Asia are driving farmers to look for alternatives to the traditional farming practices without reducing their cropping area. These processes also apply to the rainfed and mountain areas.

2.2 Rainfed cropland

28. Rainfed agriculture is important in large parts of northern and central Kazakhstan, where mainly spring crops are grown, i.e., mainly spring wheat. Rainfed winter grain crops are more common in the southern and south-eastern parts of Kazakhstan, where the climate is less severe and winters are milder (CIMMYT 2008). The baking quality of Kazakh rainfed wheat is very good (Suleimenov and Thomas 2006) and is the reason why Kazakh wheat is

often used to improve flour quality in neighboring countries, especially Uzbekistan (Rudenko 2008).

29. Grain production in the northern areas started on a large scale during the 1950s, when 25 Mha of rangeland and pastures were converted to wheat production. During the years of independence, and with the liberalization of the economy, many changes occurred in the structure of the production systems. Most cropland was privatized in Kazakhstan and state farms were transformed into various kinds of private businesses. These changes led to a dramatic reduction in cropped area as many farmers left agriculture.

30. The generally adopted cropping systems in northern Kazakhstan are the rotation of spring wheat with a summer fallow practiced once in three to five years. Such summer fallows are common as they are thought to preserve water in the soils for next year's crop. However, this has been proven inefficient and unsustainable, especially as these summer fallow areas are highly susceptible to wind erosion and organic matter decrease (Suleimenov and Akshalov 2006). Thus, soil fertility has significantly decreased in large parts of the rainfed territory (CIMMYT 2008, Saparov personal communications).

31. In other parts of Central Asia, rainfed agriculture is practiced on sloped land from 0.2 to 10% inclination. In these systems, agriculture is mainly threatened by water erosion lack of appropriate maintenance of soil nutrients, and excessive tillage (see also chapter 2.4 Mountains). Cultivation of steep slopes or the lack of appropriate crop management increases the problem of erosion. Because of the low productivity in rainfed systems, farmers do not have the capacity to introduce improved technologies and inputs (Oweis 2000).

32. Implementing, suitable crop rotations with economically viable crops and legumes, and measures that reduce erosion, such as reduced or zero-till systems, residue management, supplemental irrigation, contour banks, terraces, etc., can significantly arrest such degradation processes and increase the productivity of the rainfed systems. Also transferring those wheat fields on marginal land back into rangeland with traditional livestock production can potentially improve the productivity of these lands.

2.3 Rangelands

33. Traditionally, pastoral systems were practiced on rangelands spread over the mountains, deserts, and steppes, which occupy more than ninety percent of the region (Gintzburger 2004). The traditional migratory pasturing systems, with their different grazing rights during the summer and winter seasons, were discontinued after independence. These lands are now in various stages of land degradation and land right, and are unable to support livestock production to their full potential. Decades to centuries of overgrazing have taken their toll on the sustainability of the land (e.g., Mongolia, Normile 2007). Heavy grazing

pressures, loss of biodiversity, depleted fertility, soil compaction, and lack of water have adversely affected the productivity of the pastures.

34. Integrated livestock production systems provide farmers with the flexible capital they need for farm operations and to meet routine household requirements. Livestock performance can be considerably improved by focusing on alternative feed resources, especially during periods when native vegetation or forage is scarce, and through improved reproduction technologies. As soil moisture availability is crucial for shrubs and grasses in these areas, adoption of water harvesting technologies, especially in micro-catchments, can help improve and rehabilitate degraded rangelands (Oweis and Hachum 2003). Fencing experiments at the Uzbek Karakul Station have shown that pasture rotation and plot enclosure can increase fodder availability and pasture productivity by 25 to 30% (Tolib Mukimov, NARS Uzbekistan, personal comment 2008).

2.4 Mountains

35. Mountainous ecosystems cover over 10% of the area of Central Asia. Kyrgyzstan and Tajikistan are completely located in the mountains. Also in Kazakhstan, the mountainous agro-ecosystems occupy some 25.4 Mha (Regional Environmental Center for Central Asia 2004). The mountains of the Pamir-Altai and Tien-Shan of Central Asia are surrounded to the North and West by deserts. The Central Asian mountain ecosystems consist of: (i) low and high mountain deserts, (ii) semi-savanna, (iii) steppes, (iv) forests, and (v) meadows. Specific features are their extremely high biological diversity, and they represent the centers of origin for many globally important crops and animal breeds. The Central Asian mountains hold extensive natural agricultural areas (pastures, natural hayfields), water sources, and humus-rich land fit for the cultivation of fodder crops for successful livestock production. Many of these mountain ecosystems have been transformed into arable lands, pastures, and hay fields.

36. The mountains of Central Asia are the only source of fresh water in the region, and while two-thirds of the water is generated in the mountains, two-thirds are consumed downstream. Runoff from the large rivers in the regions, such as the Syr Darya, Amu Darya, Ili, Shu, Talas, Zeravshan, Atrek, Karatal, Aksu, Lepsa, etc., originate in the high altitude mountains. A cascade of water reservoirs stores water for irrigation and power generation, often generating conflicts between these uses. Many small rivers start in the foothills as a result of groundwater recharge. Their water is used to irrigate agricultural lands in the piedmont valleys. Mountain ecosystems are a source of timber and fuel wood, fruits, berries, and medicinal plants and are the habitat of various wild animals. The Central Asian mountains are increasingly displaying more pronounced signs of degradation. Central Asian glaciers have shrunk by 19% between 1957 and 1980. The glaciers surrounding Issyl-Kul Lake shrank by about 8%. If melting continues at the same pace, these glaciers may

completely disappear at some point in the middle of the 21st century. It is important to analyze the future impacts of such changes and to ensure strategic planning and forecasting of nature management implications. In large parts of southern Tajikistan, former fruit-tree areas have been completely denuded, apparently in search for firewood, as gas supply to remote rural areas is weak, and these were thrown into poverty after transition (unpublished results).

37. In the south-eastern parts of Central Asia, more than 25% of the arable lands in the mountainous regions have slopes of more than 30%. Sloping lands are affected by loss of soil fertility due to erosion, moisture deficits, run-off gullies, irrigation induced-erosion, and inadequate vegetative surface cover. There are indications that overgrazing together with relatively large geological movements of the soil in this highly motive region may lead to more heavy disruption of the vegetative cover (Reynolds et al. 2007b). Wind erosion is especially prevalent in areas where the climate is relatively dry with strong winds during cold periods. Soils in dry mountain steppes and semi-desert zones are naturally saline. Farmers have to switch to low-input subsistence agriculture and expand their fields to steep slopes. In the highlands of Kyrgyzstan and Tajikistan, at an altitude above 2000 m, potato represents the predominant crop contributing to more than 90% of household income (Pawlosky and Carli 2008). The change of land-use in this inherently fragile and dry mountain environment is resulting in severe land degradation (such as soil fertility mining, soil erosion, landslides, and loss of biodiversity), rangeland degradation due to overgrazing around villages, winter pastures, and deterioration of the unique mountain ecosystem.

38. The extremely remote, mountainous regions of Tajikistan and Kyrgyzstan are furthermore characterized by the absence of employment opportunities, a high incidence of rural poverty, and a large number of smallholder farmers living under semi-subsistent conditions. With the limited availability of arable land because of steep slopes, where cultivation leads to erosion problems and exposure to natural disasters, and a growing population, there is increased pressure on land use, thus representing a further threat to local biodiversity and land fertility.

3 Desertification and degradation of drylands

39. Drylands occupy around 40% of the earth's land area and host as much as one-third of the world's population (Qadir et al. 2008; Regional Environmental Center for Central Asia 2004; Reynolds et al. 2007a). Globally, drylands are assumed to affect the lives of about 250 million people directly and 1 to 2.5 billion people who live far from the drylands, indirectly. For example, dusts from drylands are carried over huge distances, such as dusts from the dried Aral Sea bed that have been carried into the habitable lands of Central Asia (Wiggs et al. 2003), or from the degraded steppes in Mongolia and China to China's mega cities (Normile 2007). Drylands are subject to desertification or land degradation, but the estimates of the acreage of the affected lands vary from 10 to 20% (MEA 2005) and from 30 to 70% in different regions (Safriel 2007).

40. It may be encouraging to note that, although large parts of the drylands suffer from some kind of degradation, only a small portion (78 Mha, or 1.9% of the total 3392 Mha of degraded land worldwide) appears to be irreversibly degraded (Katyal and Vlek 2000, citing Dregne and Chou 1992). Although these figures may now be outdated (no updated figures are available) there seems to be considerable scope for restorative, sustainable management for the major part of the drylands. It is also encouraging that, in spite of the complexity of the 'desertification syndrome', a limited set of factors needs to be addressed in order to achieve considerable improvements (Reynolds et al. 2007).

41. Land degradation has many definitions (for a discussion see Winslow et al. 2004). A more recent paradigm focused on a productivity-based definition in which degradation was linked to failing productivity. For example, Katyal and Vlek (2000) defined desertification as "*a condition of human-induced land degradation that … leads to a persistent decline in economic productivity (> 15% of the potential) of useful biota related to a land use or a production system*." Safriel and Adeel (2005, 2008) defined land degradation as a persistent decline in the ability of a dryland ecosystem to provide the goods and services associated with primary production. The United Nations Conference on Environment and Development defines desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variation and human activities. Desertification is the anthropogenic process of land degradation that results in losses in the capacity of soils to provide economic returns under cultivation or grazing. In other words, desertification leads to a decrease in fertile and productive land. The Global Environmental Facility (GEF 2003) has defined land degradation as "*...any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience*."

42. However, Winslow et al. (2004) correctly pointed out that although the encroachment of pastures with unpalatable bush species is seen as rangeland degradation, it may actually provide better erosion protection, and that, hence, some kinds of land degradation can reduce the negative effects on some resources. It has been shown recently that bush encroachment has positive effects on carbon storage in plant biomass and soils (McKinley and Blair 2008). Also recently, there has been considerable criticism with regard to the UNCCD definition which was perceived as too narrowly focusing on degradation instead of allowing for a more pro-active, rehabilitation-oriented view (ICARDA/ICRISAT 2008; IIWG 2007).

43. Land degradation has been estimated to cost the developing countries some US$ 42 billion per year (Djanibekov 2008; Dregne and Chou 1992); while the costs for preventive measures appear to be much lower. These figures unfortunately have never been updated, but more recent estimates are available for Central Asia. In Uzbekistan, the annual losses in agricultural productivity due to soil salinization alone have been estimated at approximately US$ 31 million, and economic losses due to land abandonment at US$ 12 million (Uzbekistan 2005). This, however, may be an underestimation, as for the whole of the five CA countries, the annual production losses due to land degradation are estimated at close to US$ 2 billion (World Bank 1998; CACILM 2006). In the initial stages of the desertification process, 'slow' variables are often responsible for the 'creeping' nature of degradation (Reynolds et al. 2007; see also Glants 1999). This explains why the process has often been overlooked.

44. Also, the key variables that define various states of equilibrium in drylands have variable thresholds for different soils. This is in contrast to the concept of one 'maximum productivity' state, which is often taken as a reference to determine the intensity of land degradation. In common with Adeel and Safriel (2007), Reynolds et al. (2007a) also pointed out that "*desertification is the emergent outcome of a suite of social and biophysical causal factors, with pathways of change that are specific in time and place*." The desertification process is seen as a degenerating spiral driven by interlinked biophysical and socio-economic factors feeding each other. Although the nature and intensity of specific degradation processes vary from place to place, Adeel and Safriel (2007) pointed out that the two components, the biophysical and socio-economic factors, are invariably interlinked.

45. Land degradation adversely affects soil fertility and crop yields. It reduces biodiversity, results in declining crop and livestock productivity, escalates production and rehabilitation costs, reduces farm income/livelihoods (Thomas et al. 2006; Saparov et al. 2007; Sanginov and Akramov 2007) and food and feed security. Furthermore, it results in loss of employment and increases the vulnerability of rural communities (Thomas and Turkelboom 2008). Land degradation is a consequence of a mismatch between land quality and land use. Land quality is affected by the intrinsic properties of climate, terrain, landscape position, landform, vegetation, and management interventions. It is well established that

inherent characteristics of land management practices and local climatic conditions determine whether the specific landscapes are resistant (stable) or vulnerable (sensitive) to land degradation. For the first time, it has been recognized that sustainable dryland management is a non-equilibrium process that requires responsive adaptation to the changing conditions. Fundamentally, it is a significant departure from all previous approaches that invariably took single-state soil equilibrium perspectives. With changing climate, not only the total amount, but also the precipitation pattern will change. Modeled scenarios developed for Central Asia seem to suggest that water, which is at the centre of all human activities, could potentially become more limiting for agricultural production in the near future. This will, in turn, drive land degradation processes and reduce ‘ecosystem services’, the ability of the land to sustain human and ecological well-being. Soils, for example, contribute to four different dimensions of ecosystem services (Barrios 2007), namely (i) the provision of goods (e.g., food, fiber, fuel, fresh water), (ii) life support systems essential to the sustainable function of natural and managed landscapes (e.g. soil formation, nutrient cycling, flood control, pollination), (iii) services derived from benefits of regulation of ecosystem processes (e.g., climate regulation, disease control, detoxification), and (iv) the cultural services (e.g., recreation, aesthetic and cultural uses). The linkages between biodiversity, ecosystem function and the provision of ecosystem services in both natural and managed landscapes have been examined in a recent publication by Barrios (2007) and hence not discussed here any further. However, it is emphasized that sustainable land management research in agricultural landscapes must focus on key ecosystem services linked to the roles of life support and of regulation of ecosystem processes.

4 Proximate drivers and major types of land degradation in Central Asia

46. The National Programming Frameworks of the Central Asian Republics indicate that land degradation takes many forms, such as water and wind erosion (deflation of sand and salt); terrain deformation (gully and shifting sands); pollution; nutrient depletion; loss of plant cover and soil organic matter; soil compaction, salinity and water-logging; and degradation of rangelands and pastures (overgrazing) and forests (logging of trees, mud flows, landslides, etc.). Faulty land and water-use decisions can have enormous negative implications through changes in the regional and global hydrological cycles. Multiple causes of land degradation and the interplay of biophysical, socio-economic, and policy factors have been identified in the national program frameworks of the Central Asian countries and have been well depicted in the 'Problem Tree' of the national programming framework of UNDP (2008).

47. The 'problem tree' points to the fact that the Soviet-promoted intensive agriculture was factually stimulating land degradation (Figure 7). The three primary causes of land degradation were (i) mismanagement and over-use of natural resources, (ii) insufficiency of economic infrastructure and market mechanisms, and (iii) insufficient development of capacity and weak inter-sector coordination. These root causes directly influence the three main branches of the problem tree. The first branch points towards the key indicators of degradation of land and water resources as adversely affecting the integrity of the natural ecosystem. The second branch represents problems associated with economic infrastructure and market mechanisms aggravating rural poverty. The third branch reflects on the influence that weak institutional structure, research capacity, and public–private partnerships have on the land degradation processes. The problem tree indicates that if the land degradation processes are not tackled immediately the interplay of the main factors might have a multiplier effect to further decrease the economic and ecological efficiency of land resources. The interplay of the causative factors can easily result in negative consequences leading to (i) increasing poverty and negative population shifts, (ii) reduced food security and life expectancy and increases in healthcare costs, (iii) social, economic, and political instability, and (iv) deterioration in environmental quality (CACILM National Programming Frameworks, Uzbekistan 2006).

48. Improved productivity of available land is often undermined by erosion, soil fertility declines, pollution, salinization and water logging, and the degradation of pastures and watersheds as a result of poorly managed intensification. All these factors reduce potential yields. Yet the assets of the rural poor are often squeezed by population growth, environmental degradation, expropriation by dominant interests, and social biases in policies and in the allocation of public goods. Soil degradation through nutrient mining is a major problem, though much of it is reversible through better soil management and fertilizer use

(Helben 2006). Bot et al. (2000) estimated the area of land affected with various degradation forms in different countries of Central Asia (Table 4). Whereas salinity is a major problem in Kazakhstan, Turkmenistan and Uzbekistan, sodicity predominates in Kazakhstan and to a lesser extent in Turkmenistan and Uzbekistan. Shallow soils in sloping toposequences, found mainly in Kyrgyzstan, Kazakhstan and Tajikistan, are often highly vulnerable to irrigation-induced soil erosion and also have constraints in terms of soil fertility due to rooting depth. In the ensuing sections we focus on the major types of land degradation in Central Asia.

49. In the following sections we describe the major immediate or *proximate* drivers of land degradation in Central Asia. There are the immediate, often biophysical causes of degradation, while more complex, underlying drivers are discussed in chapter 5.

4.1 Wind erosion

50. Sandy soils with sparse vegetation and hot and arid climate are most prone to wind erosion. For example, about 80% of the soils in Turkmenistan are sandy and highly susceptible to erosion if disturbed. The principal causes of disturbance are overgrazing, vehicular traffic, and oil exploration in desert areas. Uncontrolled cutting of shrubs and trees and insufficient/uneven distribution of water points for livestock may lead to overgrazing near homesteads, followed by rapid and serious wind degradation. Deflation of particulate materials (dusts and salts) from the drying Aral Sea is a serious problem in all the five countries, but more particularly for Turkmenistan, Uzbekistan and Kazakhstan (Wiggs et al. 2003).

51. It is seldom the heavy sand particles which are lifted up, but the fine soil particles which form the dust (Normile 2007), and which may lead to health problems in the population. The causal relationships in this often cited example of the ‘Aral Sea Disaster’ are far from trivial (cf. Wiggs et al. 2003) and deserve more studies (which will, however, not be covered in this program). Nevertheless, dust erosion becomes a problem also in agricultural systems in sandy areas, which is consistent with the data presented by Wiggs et al. (2003). Under even slight disturbances, low rainfall areas with sandy desert soils become prone to wind erosion. A solution to be introduced and tested could be the adoption of natural or artificial windbreak barriers similar to those utilized in Mediterranean countries to reduce evapotranspiration rates and soil losses.

4.2 Water erosion in irrigated and rainfed lands

52. Water-driven soil erosion is often a result of inappropriate land-use and poor irrigation water management practices. Expansion of wheat production into rangelands, creation of ‘new irrigated lands’, and inappropriate use of slopes have contributed significantly to soil erosion by runoff both under irrigated and rainfed conditions. Farmers

rarely keep the residues of previous crops as mulch cover because appropriate planters are not available and there are competing end uses for the residues (energy, cooking, cattle feed). Thus, most residues are either removed or burnt, which increases soil loss from the bare surface, decreases the soil organic matter content, deprives soil biota of their energy resources and habitat, and promotes emissions of greenhouse gases (Scheer et al. 2008). In the absence of a mulch cover, the stability of sloping lands is closely linked to vegetation cover. Sodium salts in surface soils further increase the erosive power of the run-off water (Gupta et al. 1984).

53. There seems to be scope for introducing 'off-the-shelf' erosion control measures from other regions, such as contour and up-slope cultivation, and conservation agriculture techniques with residues in controlled traffic lanes. Lower erosion rates are observed in tree plantations than in the open spaces cultivated with annual crops. Especially tree crops (fruit or forest species) planted on sloping lands can reduce soil erosion and contribute to nutrient supply in those systems (Lamers and Khamzina 2008; Lamers et al. 2008). Vegetation cover, mulch cover, and a rich root and mycorrhiza density in the soil are the best protectors against erosion, while enhancing plant growth and, hence, the land productivity in otherwise already degraded sloping lands.

4.3 Salinity and water-logging

54. The Amu and Syr Darya river systems constitute the Aral Sea Basin, which occupies approx. 150 Mha. Excessive withdrawals of river water for irrigation have led to a shrinking of the Aral Sea, seen by many as a major environmental disaster. However, whereas the demise of the Aral Sea is tragic, the parallel continued secondary salinization and water-logging of the agricultural lands is of more practical concern as it affects a large number of rural people in terms of livelihoods (Kidd et al. 2000; Kijne 2005) and health (Helben 2006; Herbst 2005). The salinity build-up is a consequence of inefficient irrigation and poor drainage (Ibrakhimov 2005; Carli 2008; Conrad 2007). The ensuing excessive use of water for salt leaching leads to a vicious cycle of more salinization. Widely laid, deep horizontal drainage systems not only increase irrigation water demands (due to percolation losses), but also add to drainage water disposal in the deserts. Discharge of drainage effluents in tributaries of the rivers deteriorates the quality of irrigation water downstream, which in part is also a transboundary problem.

55. Since the 1970s, the levels of salts in river water have increased steadily as a result of the discharge of drainage water from irrigation schemes back into the river systems. In the past, an extensive artificial drainage network was developed to address the problem of high water tables and covered about 5.7 Mha. However, currently the actual coverage and effectiveness of the system, which is over 30 years old and has not been serviced in the last

15 years, has been reduced to half its capacity (World Bank Uzbekistan 2008). Subsidized and area-based water prices do not provide incentives for efficient water use. A host of other reasons (night irrigation, uneven (not level) fields, inexperienced farmers, crusting soils) also contribute to excessive use of water and irrigation induced land degradation (Ibrakhimov 2005; Ibrakhimov et al. 2007; Forkutsa 2005).

56. Overall, 40 to 60% of irrigated soils in Central Asia are salt-affected and/or water-logged (Qadir et al. 2008). For the rehabilitation of salinity-prone environments, such areas need to be properly characterized for wider adoption of salinity tolerant crop cultivars together with relevant interventions of improved agricultural productivity. Introduction and evaluation of salt-tolerant tree, medicinal and aromatic plant species in salt-affected environments, and developing the marketing options for the produce, are imperative (e.g. Lamers et al. 2009a; 2009b; Lamers and Khamzina 2008).

4.4 Overgrazed rangelands

57. Natural rangelands and pastures constitute 70% of the land area in Central Asia. The principal livestock categories are sheep and cattle. In the arid lands of Turkmenistan, Uzbekistan and Kazakhstan, large-scale farming is practiced with sheep, goats, camels, and horses. Herd management is based on autumn-spring grazing of communal pastures close to the villages, plus summer grazing on distant, higher slopes. Winter feeding of the animals is mainly pan feeding on hays and feed blocks. Inappropriate flock structure and poor pasture management, grazing schedules, and overgrazing deteriorate not only the natural vegetation, but also the quality of forages in pastures. Mismanagement of watering points causes water-logging and secondary salinization of the pastures. Many forest areas are open to unregulated livestock grazing and the uncontrolled felling of trees. Mudflows and landslides are common in the highlands of Kyrgyzstan and Tajikistan, with large-scale deforestation and overgrazing on steep slopes being the main reasons.

58. To address this, farmers can improve the pasture management (area rotation, silvi-pastoral systems) by growing self-regenerating leguminous crops to improve soil fertility, surface cover, and livestock feeding. Industrial sub-products have been used extensively in other areas of the world, such as feed blocks in northern Africa, cottonseed in West Africa, and fodder trees in Niger. High quality fodder shrubs that are easy to grow and that generate net returns have already been adopted by about 100,000 East African smallholder dairy farmers. In Niger, agro-forestry initiatives have led to a remarkable recovery of degraded soils and provided livestock feed on about 5 to 6 Mha (World Bank 2008), indicating that sustainable land management technologies can bring about large benefits and may likewise do so under a wide range of conditions in Central Asia. Improvement and protection of community hayfields, establishment of hay and fodder funds, and preparation of additional

fodder for the winter are reported to have helped reduce animal losses by an average of 6 to 12%.

5 Underlying drivers of land-use changes in Central Asia

59. While the biophysical factors described above give the immediate causes of degradation, they are intertwined with major global trends, e.g. of climate, and with institutional, economics and policy drivers, to form a coupled human-environmental system that is underlying the proximate drivers. While this is a common phenomenon of managed ecosystems, the underlying factors and drivers in the transition countries are of peculiar nature and are discussed in the following sections.

5.1 Economic and policy changes

60. The collapse of the Soviet Union led to large policy changes. One example is the breakdown of large collective farms and cooperatives into individual and small farm households. The new geo-political situation also led to a disruption of earlier trade arrangements for the distribution of farm products. The transition from the centralized economy (collective farming) to more market-oriented frameworks (private farming) involved a large number of institutional and organizational changes. For example, during the first years of transformation of the agrarian structure in Uzbekistan there was a re-definition of land tenure, mainly the dismantling of the sovkhozes (State farms) and kolkhozes (a form of collective farming) into private land holdings (Wehrheim 2003, Khan 2005, Pomfret 2000). The land reform resulted in a vacuum with respect to agricultural services that were previously provided by the state (Kandiyoti 2004). The absence of an organization for local water management led to the establishment of Water Users Associations from 2003 in an attempt to bridge the gap between the higher-level water provider and the farmer (Zavgorodnyaya 2006).

61. Although land reforms and farm privatization sought to boost the agricultural sector, a new class of farmer was created that had never run a farm enterprise before (Trevisani 2008). New farmers have little knowledge and access to good, standard practices, let alone best practices, as extension systems are virtually non-existent. Large agricultural implements became obsolete, unserviceable and inappropriate for the small farm holders. Because of a general lack of funding, there are difficulties in adjusting the new smallholder production systems to sound principles of crop–livestock husbandry. Some countries (Uzbekistan, Turkmenistan) face strong government control in agriculture, which stifles initiative, but also represents a safety net for farmers in need of working capital.

62. Policies, institutions, and markets have a significant influence on land degradation and thus improvements of drylands. Insecure land tenures and property rights, virtual lack of extension systems for dissemination of best practices, and resettlement policies all seem to worsen land degradation problems. Farmers generally lack access to research information, infrastructure, and value-added services, limiting their ability to produce more profitably and

use natural resources more sustainably. Exchange rate devaluations and reductions in fertilizer subsidies reduce the ability of the farmers to use costly external inputs. Similarly, subsidies on irrigation water, night irrigation practices, etc., promote excessive use of irrigation water and cause secondary salinization and water-logging. Institutional aspects govern the use of water resources much more than rationale decisions on water use (Carli 2008; Conrad 2007; Zavgorodnyaya 2006). The actual implementation of sustainable land management strategies will depend largely on a better understanding of these constraints, and on attempts to improve their legal and institutional basis.

63. In the past, research institutions in Central Asian generally focused on narrow disciplinary areas, such as crop improvement, nutrient and water management, soil amelioration, and pest and disease management, with little attention given to integrated cross-cutting research topics, socio-economic and policy issues and their impacts on the livelihoods of people. Therefore, SLM approaches are needed which provide immediate incentives and provide options to combine social (markets, institutions, enabling policy environment) and technical innovations promoting sustainable land management and facilitating rural development.

5.2 Demographic pressure and poverty

64. The total population in the region increased from 56 million in the year 2000 to 61 million in 2006 (Asian Development Bank 2007). This population increase was accompanied by opportunistic migration of people into and out of agriculture (new land owners vs. rural exodus). Population growth was high in all Central Asian countries in the 1990s, and continues to be so in Tajikistan (with 2.1% population growth in 2006), though growth has been slowing down in Uzbekistan, Turkmenistan, Kyrgyzstan, and Kazakhstan (Asian Development Bank 2007). However, the high proportion of young people (in Uzbekistan 64% of the population is below 30 years of age) represents a challenge for development. Increased food demand due to high population growth rates will prompt further expansion of irrigated lands, whilst increasing the risk of water scarcity (MEA 2005). Also, there is increasing urbanization pressure on agricultural land. For example, Pandya-Lorch (2000) foresees an increase in cereal demand of 33% and in meat demand of 45% between 1995 and 2020. Gradual efficiency increases in land use and relative crop yields will not be able to keep pace with such steeply rising demands.

5.3 Climate change

5.3.1 Global warming and climate change

65. Global warming effects are due to three major greenhouse gases (GHGs); carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Warming effects of one ton of CH4 equal that of 21 tons of CO_2 and those of 1 ton N_2O that of 310 tons CO_2. Central Asia's contribution to global warming is already not negligible, for example, Uzbekistan is the most CO_2-intensive economy in the world, and Kazakhstan is the 30th largest emitter of CO_2 worldwide (Perelat 2007; citing WRI 2005). The continuation and exacerbation of land degradation in Central Asia may therefore result in significant releases of CO_2 and other trace gases to the atmosphere with possible effects on the global climate change (Johnson et al. 1999).

66. It is often hypothesized that the vast rangelands of Central Asia can serve as an important sink for atmospheric CO_2 (Suleimenov and Thomas 2006). Overall, Lal (2004) estimates that the potential of soil carbon sequestration in Central Asia is 10 - 22 Tg C y^{-1} (16±8 Tg C y^{-1}) for about 50 years, and that it represents 3%-6% of the total CO_2 emissions of the Central Asian countries in 2004, equal to 391 Mt CO_2 (based on the CO_2 emissions data presented by Robinson and Engel (2008) who cite the UNDP (2008). However, much of the literature is overoptimistic with regard to these options.

67. Worldwide, drylands cover 40% of the globe's surface. They may contribute 0.23-0.29 Gt of C per year to the atmosphere (Lal 2001), i.e., 5% of the global emissions from all sources combined. Plant biomass in drylands is low compared to other ecosystems (6 kg m^{-2} vs. 10-18 kg m^{-2}), but total dryland soil C reserves comprise 27% of total soil organic C reserves worldwide. Dryland soils are seen as C-depleted and therefore would hold a large capacity for carbon. However, this may be difficult to achieve as the sequestration of C in soils is a slow process, and the biological agents may not be in place after decades of degradation. Furthermore, the costs of storing C in soils are often overlooked. They would be equivalent to the value of the fertilizers needed to secure this carbon in humus molecules. Passioura (2008) calculated this value at 200 USD per ton of humus, while the benefits would be less than 40 USD t^{-1}. This author optimistically used 20 USD t^{-1} carbon as a price, while the current price is 3-5 USD t^{-1}, resulting in an even much smaller benefit. However, the level of climate change adaptation strategies into national framework plans is still low. Few projects are operating in countries with large dryland areas (Tennigkeit and Wilkes 2008).

68. Irrigated agriculture is a significant source of GHGs. High emissions of N_2O are produced from cotton and wheat fields, and even higher amounts of CH_4 are emitted from flooded rice fields. Soil N_2O fluxes (the level of N_2O emissions produced by the soil) vary during the cropping season, depending on soil properties and fertilizer and irrigation

management. However, measurements show that under current management practices, these emissions can be as high as 80-95% in cotton and wheat as commonly N-fertilizer applications are directly followed by flood-irrigation (Scheer et al. 2008). Irrigated rice fields had the highest GHG emissions of all crops, i.e., 10.1 kg of CO_2 equivalents per hectare per day (Scheer et al. 2008). Although rice is only covering about 200.000 hectares in the whole of Central Asia, it is unlikely that rice production will be abandoned, as rice is one of the most important crops for the households in the region (Veldwisch 2008). Instead, rice growing systems should be developed which use less water and help to reduce GHG emissions, e.g. “dry rice” production.

69. The Clean Development Mechanism (CDM) under the Kyoto Protocol allows Central Asian countries (CAC), which are Annex II countries, to participate in the global carbon (C) sequestration effort by selling C units gained from re- and afforestation to interested industrial parties (Robinson and Engel 2008). However, this requires research into eco-physiological, socio-economic and policy aspects of agroforestry and other large-scale tree plantation schemes to address not only the bio-physical potential in the region’s varying ecosystems for C sequestration such as land and tree species suitability and afforestation techniques, but also the socio-economic incentives and policy options of local afforestation projects under CDM (Khamzina 2008, unpublished report).

70. However, there are many researchable open issues and obstacles before the C sequestration potential of rangelands can be securely assessed, including, in addition to those mentioned, the current undervaluation of rangelands and forestlands as productive, the lack of knowledge, farm equipment and capital, and the fact that C sequestration in soils is currently not eligible for CDM. However, as the “climate train” (Bals 2009) chuffs on, new mechanisms are currently being developed that may provide more promising options in the near future.

5.3.2 Climate change trends in Central Asia

71. Temperature increases in Central Asia have been above global average, as exemplified by an average temperature increase of 1.2 to 2.1 °C in the region since the 1950s. Country reports to the UNFCCC (Table 6) have documented this trend, which is also visible in the climate dynamics over the last 100 years (Figure 6). This regional temperature increase is far above the predicted 0.5 °C increase in global temperature during the period (Giese and Mossig 2004), or the Asian average increase of 0.7 °C (Watson et al. 1998). Average July temperatures in Muynak, Uzbekistan, increased from 25.7 °C to 28.3 °C between 1960 and 1985 (Vlek et al. 2003). Generally, climate change predictions for this region suggest that summers will be warmer and winters colder which limits cropping options (IPCC 2007). The mean annual temperature throughout Central Asia up to 2080-2099 is expected to significantly increase by 3-4 °C (4th IPCC report). However, although various predictive

models have been developed for this region, they are not yet satisfactory. Hagg et al. (2007) therefore compared five models to predict climate change in Central Asia under CO_2 doubling. The model which fit real current climate data best was GISS, which predicted an increase of 4.2°C in temperature and a 17% increase in rainfall for the region as a whole with a doubling of CO_2 levels.

72. In addition to the direct effects of the GHGs on climate, an increase in surface temperatures has important consequences for the hydrological cycle, particularly in regions where water supply is currently dominated by melting snow or ice (Barnett et al. 2005). Mountainous regions of Central Asia, at latitudes greater than 45º North, are known to contribute to snowmelt river flows. Glacier-melt run-off has already increased by 15% in the period between 1959 and 1992. Such extra run-off may persist for decades, and in very large glaciers, such as those found in CA, even for a century or more, as confirmed by Working Group 2 of the ARP4 (Cruz et al. 2007) and in more general terms by Bates et al. (2008). This may increase the total run-off in the region, but it is predicted that patterns change: early spring run-offs may increase while summer run-offs will decrease. For example, if the CO_2 levels double, it is expected that the Amu Darya and Syr Darya basins will lose 40% and 28% of their run-off, respectively (Robinson and Engel 2008). Obviously, this would pose a serious threat to crop production during the critical phases of the vegetation period when crop water requirements have to be met by extracting irrigation water from those rivers. As water use is also expected to increase (cf. section 4.3), the coupled effects of climate change and water availability will strongly threaten the overall water availability for crop production (McCarthy et al. 2001).

73. Global warming has a direct effect on stream-flow seasonality, and warming induces changes to the evapotranspiration effect on regional water availability. Rainfall is already variable and uncertain, and the region is subject to periodic drought. Food security will depend on irrigation supplies and on new agronomic and crop management options and the capacity of farming communities to adapt them to their needs. As for the precipitation pattern, it is likely to be more differentiated than generalized models suggest: There will be an increase in most of Central Asia (5-25%), with the highest increase in the North and a relatively small decrease in the South (-5%), is likely to be expected These varied patterns have been observed in Uzbekistan where there was a significant increase in rainfall in the lowland areas, but not in the mountains and foothills. In Tajikistan, precipitation has increased at higher altitudes in Karategin (Gharm) and the western Pamir, but decreased in arid south-western and northern valleys (ICARDA-SLMR Project Annual Report 2008). Also, seasonal patterns are predicted to change: spring and fall precipitation is likely to increase and summer precipitation to decrease in the region with increased frequencies of very dry spring, summer and autumn seasons (Cruz et al. 2007). This is consistent with observations

from Tibet, where, rainfall has decreased by 0.34 mm per year, while patterns have changed: summer rains decrease while winter rains increase (Wilkes 2008).

74. The desiccation of the Aral Sea, once the natural meteorological buffer against the cold Siberian winds during winter time (Chub 2000), has already caused the frost period in the Aral Sea basin to stretch longer into spring and start earlier in autumn, thus reducing the vegetation period from 220 to 170 days (Vinogradov and Langford 2001, Ibragimov 2007). Differentiated predictions for different parts of the basin show that the southern, mountainous areas are likely to become more threatened by heat, drought and water scarcity. Increased temperatures are likely to further increase the aridity in the region. The loss of the glaciers of the Syr Darya, Zeravshan, Markansu-Karakul, and Amu Darya river basins by 21, 24, 13 and 19%, respectively, will furthermore adversely affect the irrigation water supply during the period from May to August, the main vegetation period in the region (Uzbek Initial National Communication to the UNFCCC, unpublished). The forecasted increase in precipitation is yet unlikely to compensate the crop water deficit. Elevated air temperature and soil moisture deficits during the vegetation season will thus have serious implications on crop production and rangeland productivity both through irrigation water supplies and changes in evapotranspiration. An increased frequency of heavy rainstorms on the other hand will increase run-off and soil erosion. This is particularly important in areas with an annual rainfall of between 500 and 750 mm and where there is insufficient ground cover (Gisladottir and Stocking 2005).

75. The temperatures during winter wheat harvest in mid June increasingly exceed 40°C leading to severe yield losses and unfavorable milling properties. Increased evaporation during the growing season will further reduce the production of spring wheat by 27% or more. An increase in the total number of days with temperatures above 40°C is likely to prove unfavorable also for melon and watermelon and decrease cotton yields by 10-40%. This illustrates the need for introducing more drought resistant crop varieties and water-conserving agricultural measures.

76. Productivity of the rangelands in the (i) non-mountainous arid areas with desert vegetation, (ii) semi-arid regions currently used for summer grazing, and (iii) sub-humid areas with steppe vegetation is projected to be adversely affected by climate change. It is expected that the composition of plant communities in the rangelands used for pasture are significantly altered. Robinson and Engel (2008) also indicate the possibility of significant decreases in forage biomass up to 20% or more, except in mountain rangelands where the rise in temperatures could positively influence the pasture productivity. This is expected to directly decrease lamb production by 5-25% and wool production by 10-20% (Robinson and Engel 2008).

77. Expected lower annual rainfall due to climate change would add an additional layer of risk to these ecosystems that are already prone to land degradation (Popp et al. 2008). The seasonal timing of rainfall is reported to influence animal live weight and survival to the end of the year (Richardson et al. 2007), thus requiring different management strategies (Rodriguez and Jameson 1988).

78. Summarizing, global warming will have major implications for agriculture in Central Asia. Central Asia has become warmer more quickly than the global average. It is predicted that these trends even continue, and are likely to have effects on glacier run-off water availability, but varying effects on patterns of rainfall in the region and during the year's seasons. Effects on the vegetation may also be varying, yet, larger droughts are likely to cause a reduction in vegetation cover, which thus affects options for mitigation and carbon sequestration in vegetation and soils of the region. However, estimations of these effects are often exaggerated in the literature. Therefore, it may be best to follow the UNDP approach and try to harness synergistic effects, e.g. put the emphasis of efforts on regions where carbon sequestration can be coupled with effects on biodiversity conservation or other benefits, such as erosion control, or watershed protection. Furthermore, emphasis of *mitigation* and *adaptation* measures to climate change should be turned into the overall preservation of a productive vegetation cover in mountain areas, and water-saving measures in the irrigated croplands where much of the food is grown.

79. The poorly trained farmers have little experience in adapting existing practices to climate change. The combined effects of higher average temperatures, greater variability of temperature and precipitation, more frequent and intense droughts and floods, and reduced availability of water for irrigation can be devastating for agriculture. Especially drylands are particularly vulnerable to these effects. These changes will have significant implications for crop and rangeland-livestock production. This calls for new crop varieties, water-saving practices, technologies that sequester more carbon and reduce soil erosion, diversified rangeland management strategies and approaches to help farmers adapt to and increase their resilience for climate changes.

5.4 Competition for water

80. Access to water and irrigation is a major determinant of land productivity and the stability of yields. Currently more than 85% of the fresh surface waters are used for irrigating the agricultural crops in a little over 10 Mha. Demand for water for both agricultural use, and the non-agricultural needs of the rapidly growing industrial sectors and urban populations, is rising, and water scarcity is becoming more acute each passing year. As available water resources are already over-used, further development of water resources will be limited – and only possible through intensive drainage water re-use. In Central Asia, at present, the

downstream countries of Uzbekistan and Turkmenistan consume 83% of all the water of the basin (WWF 2002). The upstream countries (Tajikistan and Kyrgyzstan), where most water is generated, will be increasingly claiming the water resources for themselves. Further demand will be created should Afghanistan develop its irrigation systems at the Amu Darya, which may divert up to 10% of the total water budget of the region (compared with roughly 2% today). The lowlands in the watershed are particularly vulnerable to increased water diversions upstream. To cope with the frequent water shortages in the spring and summer season, farmers are required to adjust their agronomic and crop management practices and water management urgently needs to be improved, which would require changes in policies.

81. The changing climate, especially the temperature increases, are likely to further increase the crop evaporative demands for water which poses yet another constraint in sustaining the productivity of irrigated agriculture. Management strategies must follow integrated water management principles and improve water productivity, meeting the demands of all users (including the environment), and reducing water pollution and the current secondary salinization (McCarthy et al. 2001; Martius et al. 2008). These strategies depend on implementing incentives for efficient water usage, effectively devolving water management to local user groups, investing in better technologies, and regulating externalities more effectively. Present schemes do not support this (e.g., Zavgorodnyaya 2006).

82. Socio-economic and policy research should be geared towards creating general policy decisions on the extent to which CA countries want to rely on self-sufficiency for food crops, which have a high water demand, but give low returns. Or should the system be changed to producing more cash crops so that the present revenues of the whole system can be generated on much smaller areas? Also, the build-up of in-country processing industries will help to harness more benefits in the value chain, releasing the pressure on the natural resources (e.g., Rudenko et al. 2008).

5.5 Low productivity

83. The production of raw cotton per hectare in Uzbekistan in 2007 (2.6 t ha^{-1}) was above world average (2.2 t ha^{-1}), but only 58% of the leading per-hectare-producer Australia (4.4 t ha^{-1}) (FAOSTAT 2009). Reasons for the lower yields are repeatedly related to the extensive irrigation and subsidized crop production campaigns (e.g., cotton) of Premier Khrushchev in the late 1950s (Virgin Lands Program), which encouraged unsustainable agricultural practices, and crop monoculture causing soil degradation, salinization, and waterlogging (e.g., Glantz et al. 1993), and low soil fertility.

84. Many areas of Central Asia are still today characterized by low fertility and low agricultural productivity in spite of the agricultural potential. This is mainly due the fact that the arable areas have been under serious pressure of overgrazing and drought, but also

continuous unbalanced crop rotations, and unsustainable agricultural practices take their toll. Improper nitrogen (N) fertilizer timing in Uzbek cotton production decreased the fertilizer use efficiency by 22 %, directly causing a decrease in farmers' yield and income (Kienzler 2009).

85. Also changes in the economical setting after independence and the agrarian reforms had a negative effect on the productivity (Mueller 2006). Decreasing use of agricultural inputs (Djanibekov 2008), deteriorated equipment and irrigation systems (Conrad 2006), electricity cuts, harvest delays, etc., contribute to the decline in overall productivity. Some countries in the region have implemented major efforts to become independent producers of staple crops, but productivity and also crop quality (e.g. the baking quality of bread wheat) are not necessarily adequate for crops grown on saline soils.

86. Low crop productivity adversely affects soil carbon stocks, nutrient storage, and the carbon (C) energy inputs that drive many biological soil processes, and subsequently reduce soil fertility and cause deterioration of the soil's physical properties resulting in land degradation. To maintain yields, farmers need to use more inputs to obtain the same crop yields they used to get in the past.

87. Due to the critical level of land productivity, there is an urgent need to alter the current soil and crop cultivation practices in favor of resource-conserving, conservation agricultural-based practices to better sustain soil fertility. Experiences from northern Kazakhstan (Suleimenov 2008) and north-western Uzbekistan (Egamberdiev 2007) have shown that adjusted resource-conserving technologies (RCT) can serve as an excellent strategy for improving land and water management, and increase crop productivity, while being economically profitable. RCTs include an array of practices, including no-till and minimum tillage approaches, crop residue retention and crop and rotation diversification. Across the Central Asian region, data indicate that minimum tillage can lead to fuel savings of around 50-75% as compared to conventional tillage, and net benefits increased by around 24 USD per hectare (Pender et al. 2009). Reduced-till/zero-till planting systems have also successfully been tested for a variety of crops including winter wheat, cotton, mung bean, and maize (Gupta 2009). Recent findings in northwestern Uzbekistan (Egamberdiev 2007) showed particularly an increase in soil organic matter, improvements in soil structure and greater soil moisture holding capacities for fields with residues without losing yield of winter wheat, sunflower and maize. Furthermore, relay-planting or intercropping systems have shown great potential to significantly increase the system's productivity for various crop combinations including cotton + mung beans and maize + legumes, etc. (Gupta 2009).

88. Overall, these conservation practices are considered an innovation process with the aim of modifying conventional crop production technologies to the respective agricultural system while providing a platform for diversification and sustainable intensification.

89. Furthermore, results of the joint IWMI-ICARDA-ICBA ‘Bright Spots’ project (2008), point to the possibilities of improving inherent low fertility of some magnesium-rich soils in southern Kazakhstan through the application of phosphogypsum, which is a readily available by-product of fertilizer production in the country (Vyshpolsky et al. 2008). Following up on this would therefore represent a major avenue of soil improvement in the affected region, with very positive consequences for farm incomes.

5.6 Low crop diversity

90. Notwithstanding the constraints of soil fertility, salinity, and water-logging, farmers continue to grow a few dominant crops, such as cotton and wheat. Very few alternative crops are being used. In fact, in spite of being privatized, in some countries agricultural land cannot be freely managed by farmers because of rigid state controls which impose strict land use policies.

91. Seed systems for alternative crops, important for enhancing crop and agro-ecosystem diversity, are generally also lacking. In the downstream areas, where salinity and water-logging are becoming more acute problems each year, rice brings prosperity to some farmers, but is not sustainable due to its very high water use. Legumes are under-represented in the crop portfolio; however, they would contribute to a more balanced diet and have positive effects on soil fertility (contribution from atmospheric nitrogen). Their acceptance in the region is low. Increasing this acceptance would require changing food habits through major efforts, such as publicity campaigns. Furthermore, breeding erect varieties that facilitate the harvesting process, would further increase its acceptability. Nevertheless, the combined benefits of soil improvements and export orientation (Turkey and South Asia are major chickpea markets) are worth exploring. There is a need to develop land use plans employing an integrated approach to crop–livestock production in watershed perspectives.

92. The scarcity of (especially high-value) fodder has been aggravated due to replacement of alfalfa/wheat by wheat and the discontinuation of alfalfa grazing in winter. Re-introduction of forage legumes, dual purpose cereals and maize (grain, green fodder), other fodder crops (e.g., pearl millet, sorghum), and intercropping with legumes (maize + cowpea / mung bean; cotton + mung bean, etc.) can significantly alleviate grazing pressure on rangelands and facilitate their rehabilitation.

93. Cultivation of potato could become a possible and economically interesting alternative in the lowlands to reduce summer fallow practices between two consecutive wheat crops, thus increasing the land use ratio. Of course, this would become the practice when more drought and heat tolerant potato varieties are developed. This is envisaged by a project

that CIP is implementing in the South-West and Central Asia region, namely in the countries of Tajikistan and Uzbekistan[1]. Because CIP safeguards the world's most important collection of potato biodiversity, on which virtually all potato-growing countries have drawn to develop improved varieties, there are realistic chances of success in generating potato varieties able to withstand abiotic stress (Watkinson et al. 2006).

5.7 The national agricultural research systems: crisis of research

94. The collapse of the Soviet Union has also had a considerable impact on agricultural research. Research systems previously staffed by highly qualified and trained scientists have seen a significant exodus of staff due to the shortages of research funds. Lethargy prevails among those left.

95. Salaries in research are low and financial resources for research in the institutes are lacking (Alimgazinova 2009). The former capacity building and reward systems have been abandoned, so that staff renewal is difficult. The culture of centralized decision making stifles initiative. Due to these low incentives and the often very strong hierarchical barriers, young scientists are reluctant to work in agricultural research systems, and the average age of research staff at most of the institutions is above 60 to 65 years (Alimgazinova 2009). Lack of contact with the international scientific community and English language deficiencies have caused a technology lag and prevented scientists from keeping abreast of scientific advances, thus depriving them of the benefits of international public goods. The level of coordination and the linkages within and between national agricultural research systems (NARS) are weak and scientists feel isolated. Initiatives such as the Central Asian and the Caucasus Association fo Agricultural Research Institutions (CACAARI) are only just on the rise.

96. In the past, researchers generally performed extension functions, but the system has been losing its impact since, after the breakdown of the Soviet Union, the former channels of knowledge transfer have also broken down (cf. Wall 2008). Central Asian republics have 7,000 agricultural scientists on their payrolls (Paroda et al. 2007), but these are neither trained nor technically enabled to serve the many small farm holders that have sprung up following independence. Researchers now have no formal channels through which to disseminate information, knowledge, and new technologies. Research programs are required to be realigned to the needs of small to medium size holdings, and market opportunities. The NARS themselves recognize that they cannot do this alone and would require the assistance of the international community.

[1] The project on 'Enhanced food and income security in South-West and Central Asia through potato varieties with improved tolerance to abiotic stress' started in January 2008 and is scheduled to run for three-years.

97. A specific problem is the urgently needed upgrading of many research institutions with technologies and skills. In soil science in particular, paradigms carried over from Soviet times include different soil nomenclature and outdated and obsolete laboratories. The majority of the soil and plant laboratories operate still according to Soviet standard procedures which are expensive as they require large amounts of chemicals, glassware and staff time. The chronic lack of funds to carry out research and analysis impedes the timely updating of maps and hampers the real-time appraisal of ameliorative measures. The Soviet procedures furthermore do not necessarily match international procedures. The current conversion of the results to international scales, e.g. the soil texture classes, can be seen more as an approximation, while the reliability of the analyses of soil organic matter, mineral nitrogen content, etc. is not satisfactory and has to be further confirmed before these data can be used for calculating potential carbon sequestration. Outdated soil maps hinder development of soil salinity amelioration and sustainable land management in general..

98. Further problems are the non-availability of young candidates for the positions of breeders, and the lack of staff trained in modern pest and disease control methods. As new crops move in, new pests and diseases appear, most Central Asian countries are ill prepared to handle genetic enhancement and the IPM issues of diversification of crops. Also the non-availability of capacity building in GIS and remote sensing has become an increasing and pressing problem especially as there are no universities offer courses in this discipline. All of the above is slowly being overcome, but needs continuous efforts from both national systems and the international community.

5.8 Public–private partnerships and input supplies

99. Although the Central Asian countries are gradually reforming their economies, there is no sizeable private sector that invests in agriculture. The private supply sector, in general, is weak as well. Working public–private partnerships are few. Inputs to agriculture are still regulated largely by the state (Veldwisch 2007). In many countries there is an urgent need to involve the private sector for the evaluation of quality seed systems. An informal seed system exists in certain countries, but would need to be improved in aspects like quality control by applying the procedures envisaged by FAO to obtain the so-called Quality Declared Seed that would represent an improvement to the existing situation, especially in countries where there is no official certification system. In addition, strategies to develop plant genetic resources (PGR strategies) need to be harmonized.

6 Sustainable land management (SLM) in Central Asia

6.1 The SLM concept

6.1.1 Regional priorities for SLM research in Central Asia

100. To address the consequences of globalization, rapid climate change, and increasing food prices, together with a renewed focus on research for rural development, new agri-food research paradigms (e.g., 'from farm to fork' – from production to consumption), and the revolution in information technology, it is of paramount importance that the right agricultural research priorities be defined. It is also important to capture the dynamic nature of the evolutionary process of agricultural research in the region. In developing the regional SLM priorities outlined in this Research Prospectus, a wide range of documents[2] was revisited, and aligned with the CGIAR system-wide priorities and the Millennium Development Goals (MDGs) using a production system based, agro-ecological approach. The emerging common regional priorities, in the context of sustainable land management research (SLMR), have been identified (Table 5).

6.1.2 Strategies for mitigating and adapting to climate change

101. In view of the importance of climate change for the region, we discuss first the needs for the Central Asian nations to develop research programs for the two strategies of mitigation of and adaptation to climate change, as far as agriculture, land use and rural livelihoods are concerned.

102. **Mitigation** (reduction measures) strategies include reducing fossil fuel burning by shifting to conservation agriculture (e.g., reduced tillage and controlled trafficking), reforestation and afforestation of relatively unproductive arable lands, reducing the burning of crop residues, and the use of biogas plants for heating and cooking.

103. **Adaptation** strategies include changing the cropping systems and patterns, switching from cotton–cereal-based systems to cereal–legumes systems and diversified production systems of higher value crops and promoting more efficient water use. The latter include an increase of water use efficiency through supplementary irrigation systems, more efficient leaching and irrigation practices and the adaptation and adoption of water harvesting technologies. The adoption of conservation agriculture in dry areas is often thought to be

[2] Papers from round table discussions held in 2008 in Tashkent, the Strategic Plans for Dry Areas in the CWANA Region 2007 (ICARDA 2007), The Proceedings of a Regional Research Need Assessments (RNA) (Paroda et al. 2007) and the Report of the Consortium-Commissioned External Review (CCER) of the CGIAR Program for CAC (Fereres et al. 2008).

limited by low biomass production, but current evidence suggests that even small amounts of residue retention can significantly improve soil properties, reduce evaporation and decrease the soil's susceptibility to erosion. These options must 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 (Thomas 2008a).

104. To increase the resilience of production systems to climate change impacts, efforts must also be directed at creating flexible policy and institutional environments for enabling decentralized decision making on crop choices and agronomic practices by farmers in some of the countries in the region.

105. Adopting the ideas of Kruska et al. (2003) to our circumstances, we consider that there is a need to develop regional and national climate change databases that can assist in assessing the potential impact of climate change across various agro-ecologies and production systems of the region, their interactions, the evolution of socio-economic and livelihood dynamics as a result of these changes, and possible adaptation and mitigation measures at regional, national and household levels. These measures thus need to be designed to lessen the negative impacts (e.g., heat/cold stress, changing precipitation patterns). One of the benefits of such databases would be in the identification of hotspots of change and prioritization of mitigation and adaptation measures on these hotspots.

106. Several authors suggest wider-ranging critical actions for mitigation of and adaptation for climate change. Although these are in part developed for China and Tibet, they apply to Central Asia, too. Practical suggestions by Jianchu (2008), particularly for rangeland management, are a) to develop integrated research to understand the complexities of highland management; b) to promote regional cooperation and science-based dialogue to regulate water flows (this is a highly critical aspect in the region); and c) to build up social resilience and offsetting the lack of knowledge by actively involving local communities; allowing their knowledge, innovations, practices, and concerns to inform understanding and help direct responses. Wilkes (2008) adds the need for developing incentive systems for sustainable grassland management. Rotational rangeland management that has been in place in the past needs to be restored. Tennigkeit and Wilkes (2008) furthermore emphasize the need to develop trust funds for pilot projects, the need for recognition of rangeland importance in national GHG accounting, and the need for better data and communication. Rangelands are often misunderstood as unproductive wasteland, and pastoralists are seen as backward, which affects their land rights. These authors present a SWOT analysis which is not all unfavorable and is applicable to Central Asia with few modifications.

6.1.3 Elements of the SLM concept and their inter-disciplinary integration

107. The purpose of any land management research oriented towards fighting land degradation is to deliver precise and reliable knowledge on technologies, economics, institutional, and policy changes that enhance sustainable stewardship of natural resources (Thomas 2008b). Sustainable land management research (SLMR) seeks to establish, based on scientific work, economically viable and socially acceptable 'production-protection' agriculture. This "new" agricultural system should further be based on four principles, (i) reduce the production risks (principle of security), and (ii) protect the multi-functional roles of drylands to provide for goods and services (protection), while at the same time (iii) being economically viable (viability) and (iv) socially acceptable (acceptability) (FAO/FESLM 1993). An alternative definition describes SLM as a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management to meet the rising food and fiber demands while sustaining ecosystem services and livelihoods (World Bank 2006; Thomas 2008b).

108. The Global Environment Facility (GEF 2003), likewise, maintains that SLM should contribute to the triple-win goals of promoting economic growth, advance social equality, and helping to achieve a balance in the competing use of land for livelihoods and ecosystem stability. Sustainable land management strategies should contribute to achieving three Millennium Development Goals: (i) ensuring a reduction in rural poverty and improving livelihoods through efficient use of natural resources, and access to affordable quality food through agricultural diversification (MDG1), (ii) achieving environmental sustainability (MDG7), and (iii) developing global partnerships for the development of the land-locked Central Asian republics (MDG8).

109. More specifically, SLM requires the maintenance of a protective biological surface cover (living plants or mulches) on a 'good' soil structure to allow gas, water, and nutrient exchange between the soil and the plants. It also requires adequate levels of soil organic matter and soil-inhabiting organisms as these fulfill many ecological functions (Thomas 2008b; Martius et al. 2007; Martius et al. 2001). Such soil cover would also contribute to reducing the greenhouse gas emissions (Scheer et al. 2008). To be effective, "these mainly biophysical perspectives need to be combined with socio-ecological perspectives whereby the driving forces behind land use decision making are clearly understood in terms of the socio-economic context, including livelihoods and markets for products, and the asset base of the land users (i.e., the use of the sustainable livelihood perspective and the principles of physical, human, social, financial, and natural capitals)" (Thomas 2008b).

110. The SLMR technologies to achieve these triple-win goals are available, but they need to be tested and adopted under the location-specific social, ecological, economic, and institutional framework conditions. Agro-ecosystems are often an oversimplification of

natural ecosystems, designed to increase, above all, crop yields. Often, very simple agricultural systems quickly develop degradation symptoms, whereas more complex-structured systems do not show any detectable degradation over long periods. SLM should, therefore, be achievable through building positive complexity into the land-use systems. Recent evidence shows that it is possible to intensify and diversify agriculture and increase the productivity of a wide range of farming systems in drylands through resource-conserving technologies (RCTs) (Noble et al. 2006) without the anticipated trade-off between resource conservation and increased production. It has also been demonstrated that this works well for irrigated drylands in Central Asia (Egamberdiyev 2007).

111. RCTs include a wide range of practices, such as no-till and minimum tillage approaches, which enable a drastic reduction in tillage operations, and thus, labor and fuel costs – a crucial consideration for the resource-poor, undercapitalized farmers who are the majority in Central Asia. Other RCTs include surface seeding and permanent raised-bed planting (which reduces the amount of seed and irrigation water needed and thus also saves costs) with appropriate technology. It further comprises mulching and residue management, the use of water saving technologies such as water harvesting, supplemental irrigation, and skip-row irrigation. The latter can be applied to cotton-legume cropping geometries and other crop combinations such as potato intercropped with maize or sunflower, as a means to alleviate the potato crop from the torrid, arid and hyper-thermic conditions of the lowlands. RCTs thus provide a platform for diversification and intensification of the production systems. Live fences and vegetative barriers, agroforestry and horticulture, integrated nutrient management, integrated pest management, integrated tree–crop–livestock farming systems, and the rationale use of sloping land (contour farming, upwards plowing, etc.) are also part of RCT. Initial results from the adoption of RCTs in the region have been very encouraging, as they have proven to enhance soil organic matter, soil life, and yields (Egamberdiyev 2007). Applying RCTs have been shown to also make ecosystems more resilient, and reduce their vulnerability to climate change. They are often seen as the center-piece of SLM, as enabling economic, institutional, and policy options can also be developed around them.

112. This research framework puts SLM at center stage and introduces SLM and RCTs principles that increase agricultural productivity ('produce more at less cost'), enhance sustainability, raise the quality of the environment and natural resources, and increase biodiversity. This strategy reflects our conviction, based on strong scientific evidence (Hobbs et al. 2007), that moving towards reduced- and no-till conservation agriculture will have profound positive impact on land management.

113. Natural resource management (NRM) problems most often have an element of site specificity and, therefore, must be resolved taking into account the socio-economic endowments of the farmers. Thus, finding unifying principles is of utmost importance for handling the NRM issues. Conservation agriculture provides a way out. Basic principles of

conservation agriculture are not site-specific, but represent unvarying objectives (marked reduction in tillage, adequate retention of crop residues on the soil surface and the application of economically feasible, diversified crop rotations) that are developed to extend conservation agriculture technologies efficiently across all production conditions.

114. For this reason, the key elements of the SLM strategy include the basic tenets of conservation agriculture which provide some major opportunities for the enhanced sustainability of agriculture. These opportunities include (1) the move from intensive tillage to no-till or reduced-till agriculture (this also reduces the need for machinery use and traffic on the field, reducing soil compaction and fuel costs); (2) the change from mono-cultures to a more diverse crop portfolio on the farm, and the introduction of intercrops and relay crops; and (3) better management of residues, which are currently either burned or grazed, to address the needs for residue retention and soil cover. These unifying principles can be easily integrated with the specific local socio-economic and biophysical conditions.

115. The major research cleavage that exists between biophysical and socio-economic domains in research is much more pronounced in Central Asia than elsewhere, because economic research capacity is limited and social or institutional research is practically non-existent. There is an urgent need for integrative research methods to fine-tune the integrated and intensively interwoven crop–livestock management practices. In order to link up the various options, a variety of modeling approaches, including the recently developed ‘minimum data’ (MD) modeling methods to screen prospective technologies for economic viability (profitability, risk), will have to be utilized. More complex, dynamic bio-economic models may prove useful wherever analysis by MD models is insufficient. The ZEF Khorezm project in Uzbekistan provides guidance on how to achieve the goal of integrating land use, policy, and institutional research through modeling. The approach will be adapted to all benchmark sites in Central Asia. To out-scale improved land management practices there is a great need to successfully develop related impact pathways and assess and monitor the effects of the measures, for example, on household incomes.

116. This research framework builds on the elements of the SLMR strategy described above. It is also based on past achievements in the development of agricultural technologies (such as in cereal-based systems and conservation agriculture), but links them, in a systems approach, to the socio-economic and institutional dimension. The strategic entry points for sustainable management of drylands necessarily have to be soil, crop and water management. With minimum or no-till and appropriate crop establishment methods, yields (biomass) and water productivity can be significantly improved in different agro-climatic zones. RCTs provide the platform for a multi-disciplinary approach to integrate crop–livestock farming systems across all production systems specific to the various dominant agro-ecologies in Central Asia that will be studied here.

6.2 Approach

117. As described in Section 2, research under this Research Prospectus should focus on the four major agro-ecological zones of the region, (1) irrigated croplands, (2) rainfed croplands, (3) rangelands and (4) mountains. In order to cover all landscape patterns, two perpendicular transects were identified (Figure 5) that represent the major agro-ecologies within Central Asia. The elements of the research framework are graphically depicted in Figure 7 (see Extensive Summary).

118. One vertical transect would cover a narrow strip extending from north Kazakhstan, through Uzbekistan and the western parts of Kyrgyzstan into Tajikistan, encompassing peri-humid to arid climates. Another, horizontal, narrow and curvilinear transect would run parallel to the southern boundary of Central Asia. While most variants of the arid/semi-arid rangelands are covered in the vertical transects, where degradation due to wind, water, and land use is more prevalent, the horizontal transect along the southern borders largely covers the mountains and irrigated agriculture, with its associated problems of soil erosion, water-logging, and secondary salinization.

119. A cost effective way for implementing SLM is to use a ‘benchmark site concept’ to create research hubs for major agro-ecologies of Central Asia. Technologies developed in specific ‘research hubs’ can be up-scaled and out-scaled to similar agro-ecologies with some fine-tuning. The selection of representative benchmark sites within the two transects will enable the upstream and downstream relations of the biophysical processes of land degradation to be established, address the potential of the soils to sequester carbon and reduce greenhouse gas (GHG) emissions, dynamically monitor land health indicators under different land use patterns, and allow up-scaling of the results from the benchmark sites to the wider region. The number of benchmark sites acting as ‘research hubs’ should be kept within manageable numbers to allow better integration of SLM technologies to improve efficiency and facilitate impact assessment.

120. The adoption of SLM strategies and programs must start with field level implementation, but needs to be supported by research on land use at multiple spatial and temporal scales. This helps to create ownership with farmers, and offers the possibility to demonstrate good practices to decision-makers. The ‘research-development continuum’ includes measures that enhance the viability of technology options through participatory technology development (cf. Martius et al. 2007) while at the same time addressing the necessary policy shifts at higher levels. For the rehabilitation of degraded lands, the indigenous knowledge of the farmers about how land and water resources respond to various interventions is of crucial importance. Adeel and Safriel (2007) and Thomas (2008b) have proposed a pathway for implementing SLM that addresses the multi-dimensional nature of this process. Viable development options should be established through participatory

approaches, for example, by applying an Integrated Natural Management (INM) Strategy that captures the technologies as well as the motivations that lie behind their adoption (or failure to be adopted) (cf. Turkelboom et al. 2002; Hagg et al. 2007; Harwood and Kassam 2003). This is a participatory process which uses so-called 'cornerstones' to achieve effective R&D in projects (Turkelboom et al. 2002).

121. Upstream land-use changes have considerable impact on downstream water services. In many watersheds, most of the runoff and silt load emanate from small but critical areas upstream. Commonly, farmers and decision-makers do not invest in implementing conservation measures in the critically vulnerable portions of the watershed. However, in a watershed approach, until land in the critical upstream area is stabilized, there is little possibility for downstream sustainability. There is a specific demand on GIS approaches to ensure that the upstream/downstream problems are sufficiently addressed in the SLM context. It follows that solutions for several NRM problems (e.g. climate change, irrigation development, up-and down-stream linkages of soil erosion, land degradation, etc.) reside in trans-boundary domains in the region. The Central Asian republics thus realize the importance of regional cooperation being facilitated by the several regional initiatives of the CGIAR and donor agencies through CACILM.

122. The priorities, research questions, objectives, and activities for SLM under the CACILM program are listed in Table 7. Furthermore, SLM will require supportive measures, such as capacity building and the build-up of crucially important infrastructure. A description on the key SLM questions listed in Table 7 is provided in section 6.3.

6.3 Research topics

6.3.1 Agro-ecological characterization of production systems

123. Work in this research framework will rely as much as possible on the existing capabilities of the partners. However, research capacities in many research fields are outdated or not available. This is especially true for three key areas needed to achieve the goals in this research program. These are (1) capacities for modern soil analysis, which are the basis for data bases and out-scaling, (2) capacities for remote sensing and processing of geographical information (geographic information systems – GIS), and (3) facilities for weather forecasting that allow responding to climate change issues in a more comprehensive manner. While the soil and weather laboratories will be set up in one of the partner institutes, which will be extensively upgraded through this measure in order to become the leading regional centers in their fields, the GIS laboratory will be set up as an integrative facility in the premises of the CAC Program in Tashkent.

6.3.1.1 Establishing modern soil data base and laboratory capacities

124. Most Central Asian countries are struggling with budgetary, infrastructural, and human capacity deficits in science. Trans-country and interdisciplinary approaches to research are therefore limited, and meta databases for integrated analyses are not available. Creating such meta databases with crop-relevant climate data (climate, crops, length of growing periods) and soil maps (soils, relief slope, and soil moisture and irrigation provisions) will allow preparing similarity maps for the efficient and economical out-scaling from the benchmark sites of the SLM technologies. Economic and poverty indicators need to be monitored in conservation agriculture (CA) (land degradation, vegetation cover, soil salinization). Finally, we intend to integrate different data types and scales through mixed effects models in a GIS framework.

125. Globally in soil science, modern technologies based on spectroscopic and electromagnetic methods are becoming increasingly popular in overcoming the shortcomings of the traditional methods, which are time-consuming and involve cumbersome sampling and costly wet laboratory analysis. Mid- and Near-Infrared measurements provide an easy, cheap and quick way to assess large numbers of soil samples in short time (Shepherd and Walsh 2007). Except for the initial purchase price, little money is needed for running the devices, as they do not require gases or chemicals. One shortcoming, though, is the constant need to calibrate. Additionally, the combined use of Reflectance Spectroscopy (RS), electromagnetic (EM) induction meter (FDEM-frequency domain electromagnetic, and TDEM-time domain electromagnetic), and Ground Penetrating Radar (GPR) provides innovative approaches for soil salinity assessment and can be coupled with modern spatial mapping methods (Barrios 2007; Ben-Dor et al. 2008). These methods complement each other by offering different observation layers; RS, EM, and GPR provide surface reflectance, rooting depth, and subsurface layer information, respectively. These devices provide instant and more accurate measurements of soil salinity, which provides quicker access to results, avoids issues of representativeness of the sampling area, and reduces overall uncertainty.

126. A fully functional, certified, regional soil laboratory will be set up at an existing soil institute in one of the partner countries in Central Asia. This laboratory will be equipped with a complete set of modern analytical hardware and software for soil analysis, and serve as the reference laboratory for all other soil laboratories in the region. It will also serve as a training center for aspiring young staff as well. It will be modeled on the modern approach pursued by the soil laboratory of ICRAF, Nairobi where analysis of soils is now almost exclusively based on the use of Mid- and Near-Infrared Spectroscopy and other modern tools, which do not require sample preparation and wet analysis and allow for a high through rate of samples. This laboratory will need to be linked closely to an international standard laboratory. Standard analytical capacities can be added where needed. This laboratory will also serve Central Asia for analytical quality control for soil, water, and air samples.

6.3.1.2 Remote sensing and GIS

127. Understanding the symptoms and assessing the syndromes of dryland degradation, as well as the necessary up-scaling from the benchmark sites to the wider area, requires modern tools for land diagnosis and assessment. Geographical Information Systems and Remote Sensing (GIS/RS) techniques and capabilities for dynamic time series analysis need to be provided through this framework program, as no capacities are available in Central Asian countries. A fully functional laboratory for GIS/RS is needed to provide modern supra-regional monitoring and research capacities covering land and water resources in Central Asia.

128. The benchmark sites under different land uses will be continuously surveyed for their status. This will be linked to the wider areas (upscaling) through similarity assessments using modern software for geostatistics (e.g. Cressie 1992; Isaaks and Srivastava 1989) and data mining (WRI 2005; Yen et al. 2004; Yohannes and Webb 1999). Thus, impact assessment can be undertaken, and the up-scaling strategy prepared.

129. In view of the scarcity of well-trained GIS/RS staff in Central Asia, this has to be headed by an expatriate who will provide supervision, guidance and capacity building to enable all countries to set-up fully functional GIS/RS capacities by the end of this project. This will include also the necessary cyber-infrastructure for web enabled information dissemination on land, water, and agro-eco-regions and the technology options for combating land degradation. This central facility will be linked to advanced research institutions as well as to the global Remote Sensing network. At present, we envisage this laboratory will be set up at the CGIAR’s Program Facilitation Unit (PFU) of the Central Asia and Caucasus Program (CAC), integrating the existing smaller laboratory at the IWMI sub-office and the incipient infrastructure of the SLMR project.

6.3.1.3 Medium-range weather forecasting

130. Forecasting and simulating the effects of the mitigation or adaptation strategies on climate change in Central Asia closely relies on the provision of meteorological data of high timely resolution in the proximities of the selected, representative SLM benchmark sites. Basic hydrological and meteorological data are generally available with the national hydrometeorological centers which derive their data from various meteorological stations in the respective country. These data however are costly, and do not necessarily cover the benchmark site surroundings. Medium range weather forecasting (MRWF) facilities provide opportunities for the farmers to do crop planning and to take appropriate advance measures to adapt to aberrant weather conditions. They furthermore guarantee reliable and high-resolution data for scientific research, modeling and the development of optimal management strategies. When MRWF is combined with other studies such as on the seasonal break out of diseases

and pests and their vectors, it can greatly help farmers to reduce crop losses through the appropriate adoption of integrated pest management (IPM) technologies.

6.3.2 Genetic enhancement of cultivars for improved crop productivity and seed systems

131. Resource conserving technology platforms require new crop cultivars that are tailored to respond to genotype x tillage x environment interactions in a more adequate way. New improved crop cultivars with greater stability and growth vigor and early maturing perform better over seasons, have the ability to compete better with weeds, and may escape the predicted drought and heat situations. There is also a need improve the grain quality for bread making, for example, in Uzbekistan, where the baking quality of the irrigated winter wheat is rather low (Kienzler 2009). Furthermore, upcoming, very virulent and aggressive pathogens and pests, such as stem rust (Ug99), yellow rust, and Sunn pest (Eurygaster integriceps[3]), must be addressed through breeding better, more resistant varieties.

132. Breeding dual purpose crops such as winter wheat, barley, and triticale, i.e. cut green biomass for fodder at the end of the year or in early spring, and harvest the grain as usual, is required to improve the availability of fodder for livestock during the critical winter time, and reduce the competition for crop residues. The introduction of diversification crops and the development of community-based seed systems in public–private partnerships will help to meet demands for improved seed of different cereals, legumes, forage, vegetable, and pasture species to increase production, improve the nutrition, and widen the horizon for the genetic potential of the crops .

133. A large number of diversification opportunities also exist in fruit and orchard crops in agri-horti-production systems practiced on sloping lands. Sorghum and pearl millet, chickpea and oilseed crops (safflower, rapeseed) are known to be drought- and salt-tolerant crops. The program will help develop production technologies for the introduction of these crops onto rainfed, irrigated saline, and range/pasture lands as adaptation strategy for the local population. These crops can be grown successfully together with salt tolerant grasses and shrubs, etc., in marginally saline, rainfed as well as in irrigated areas after the wheat harvest. This will reduce the summer fallows and achieve some control over salinity in the early stages of establishment (Minhas and Gupta 1992; Toderich and Shoaib 2007; Toderich et al. 2008). Also, on marginal fields which are taken out of the governmental state order for cotton (e.g. Uzbekistan, Turkmenistan) due to high salinity or low irrigation water availability,

[3] Sunn pest is the most destructive insect pest of wheat, causing serious yield losses in Afghanistan, Iran, Iraq, Turkey, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan

improved varieties of sorghum and pearl millet could present an additional source of income and increase the productivity of those areas.

134. Recent experiments allowed assessing the potential of various sweet sorghum cultivars for the highly salinized, arid soils of the Karakalpakstan region south of the Aral Sea (Begdullaeva et al. unpublished). Promising yields of around 5-7 tons per hectare are favorable for the prospect of using the salinized, degraded land for biofuel production without getting into competition with food production, an argument often brought forward in criticisms of biofuels.

135. Maize, pigeon pea and other grain legumes have the potential to partially meet household energy requirements (fuel) in remote areas. Furthermore, initial results in Turkmenistan and Uzbekistan with different fast growing pigeon pea varieties, have been very encouraging as erosion control measure by quickly providing surface cover for steep slopes and arid lands.

136. Aside from main field grain crops, potato as a food and cash crop seems to have significant advantages especially in the highlands, but also in some lowland systems. Potato and vegetable crops are among the most profitable diversification crops with significant potential to contribute to poverty reduction. In Central Asia, these crops are generally grown by smallholder farmers who are among the poorest group. Work is already under way in Tajikistan and Uzbekistan which shows interesting levels of tolerance to heat and drought in potato under laboratory conditions (Carli 2008). There is a need to develop improved practices (no-till and crop establishment for control of land degradation, ICM, and IPM) to promote diversification and intensification of the farming systems for a rational land use in the toposequences.

6.3.3 Land, crop and water management technologies for irrigated and rainfed areas

137. All the programs to be initiated will contribute to increasing the productivity of crop–livestock systems in all four eco-regions and land use systems, as this is where the bulk of the food is produced. These areas, therefore, represent the backbone for the national economies of the countries in the region. The strategy will be to develop, refine, and promote adoption of ‘yield-enhancing and cost-reducing’ technologies, together with appropriate water and management of weeds (grassy, broad leaf and sedges) as strategies for adaptation to and mitigation of climate change.

138. Modern agriculture has prospered and become dependent on cheap fossil fuels. Fossil fuels are used to power mechanized traction for tillage, cultivation, spraying and harvest, but also for pumping irrigation water, powering dryers and transport of agricultural products and inputs. In precisely leveled fields, water flows quicker and uniformly across the no-tilled

fields compared to the plowed fields resulting saving of water and energy required for pumping water. Fertilizer use efficiency also increases because the nitrogen and phosphorus inputs drilled with the no-till equipment rather than broadcast as in conventionally tilled wheat or cotton plots will not be lost to the atmosphere (cf. Scheer et al. 2008). No-tillage is an appropriate technology to achieve more efficient energy use in agriculture. In no-tillage, crops are planted in just one pass of the tractor or animal powered seeder/planter. Conservation agriculture (CA) practices are based on the necessity that soil is permanently covered and crops are sown through this cover with minimal soil disturbance. Specialized no-till machinery has been developed and is today widely available. Tractor mounted equipment offers many different designs from cutting discs, rotary turbo-system fitted with chisel opener tines that penetrate the mulch and open the soil for seed and fertilizer to other innovative systems such as strip till equipments that incorporate the residues and till the soil in a very narrow strip (a few centimeter wide) for placement of seed and fertilizers.

139. CA will be the focal point of all measures to be introduced and researched. It consists of an array of various approaches that can be tailored to specific biophysical situations as well as the economic conditions of the farm. The SLM strategy and the need for achieving major shifts for enhanced sustainability of agriculture and increased resilience to climate change have been described in earlier sections. In order to initiate these shifts, it will require appropriate multi-crop ferti-cum-seed drills and planters having sufficient clearance for relay planting of wheat into standing cotton, or rice into wheat planted on flat or raised-bed furrow configurations. Farmers should also be able to use these multi-purpose planter prototypes in no-till fields and the sloping lands covered with loose and or anchored residues. The program will therefore support the development of (or fine-tuning of existing) agricultural machinery for planting on the resource conserving technologies (RCTs) platforms, assist in the rational use of sloping land with appropriate crop and cultivar choices, intensification (including inter-cropping), and diversification strategies.

140. Surface retention of crop residues (mulch) is a crucial element in CA and thus of the SLM strategy for all its beneficial impacts on the soil. When applied correctly, surface mulch can buffer soil temperature changes (in winters and summers), protect the soil against erosion, promote the accumulation of organic carbon, facilitate nutrient recycling, reduce weed infestation, improve the water storage capacity of the soil, reduce evapotranspiration and hence slow down soil salinization, and provide niches for beneficial microbes, soil fauna and flora to flourish. To successfully introduce such organic surface covers as element of SLM, it is important to convey to farmers how to plant through the residues; apply fertilizer nutrients and herbicide molecules for control of weeds. Also, the competition between using the crop stubble as fodder for livestock or as surface cover have to be looked into, as they will affect the successful adoption of CA and RCTs in Central Asia. Research is needed to develop and identify new crop cultivars suited for RCTs such as stable cultivars to absorb climate change

shocks, vigorously growing competitive cultivars for effective weed management in zero till, and suitable for raised beds and surface seeding conditions. Straw quality (source of energy, food for soil biota) which likely affects the population dynamics of pest and diseases vectors is a missing link that needs to be probed in longer term study such as to develop appropriate IPM technologies for the RCT platforms.

141. Over large tracts of Central Asia, cotton and wheat constitute the predominant cropping system, generally grown in raised beds under furrow irrigation. After 50 to 70 years, the system is now showing signs of resource fatigue. Slight changes in planting geometry on the raised-beds provide options for intensification and diversification of this and other cropping systems (e.g. double cropping of mung bean with cotton; maize + potato / red beet / onion / garlic, maize + cowpea / beans, and wheat with mint).

142. The program will promote precision land leveling to save water through uniform water application, mulching and appropriate water-wise cultivar choices, etc., through the involvement of the water user associations. Skip-furrow irrigation will be further developed for management of saline environments and to avoid the need for dismantling the beds each season. Also the combined use of saline drainage and clean canal water during the leaching and irrigation periods will be studied as measure to cut back the high fresh water needs. This will be supported by adequate water management at the field, micro-basin and watershed level.

143. In rainfed areas, land and water productivity can be sustainably increased and yields stabilized by adopting supplemental irrigation. In this practice, rainwater and other resources are used together more efficiently. As supplemental irrigation improves, soil water inputs for fertility and responsive varieties may also be used. Water harvesting technologies, currently not practiced, can be used at the macro-catchment level to provide water for supplemental irrigation, including small farm reservoirs filled with runoff water. Water harvesting at the micro-catchment level can be used in the steppe areas to rehabilitate degraded rangelands and improve pasture productivity.

144. Weed management is a major weakness in improving the water productivity in Central Asia. New herbicides that are effective in control of Phragmites, sedges, broadleaf and grassy weeds are generally not available to the farmers. Farmers often have to rely on inter-cultivation or excessive ponding of water before crop planting for control of weeds. For example, farmers gradually increase the depth of standing water in rice culture for control of Phragmites. Research show that use of pre-and post emergence herbicides can significantly reduce the weed menace and help save up to 15% canal water in direct dry seeded rice (ICARDA- SLMR Project Annual Report 2008).

145. Adoption of bio-drainage measures along the irrigation and drainage networks will help control saline seeps, meet fuel needs, and improve ecological services in the

neighborhood. In order to meet anticipated shortages of irrigation water supplies, raising the rate of re-use of low-quality drainage water will be inevitable in coming years. Drainage water can be used profitably to meet crop water demands in the salt-tolerant growth stages of the crops. The program will organize research for developing comprehensive guidelines for irrigation water quality management, tailored to the cropping systems.

6.3.4 Integrated livestock–rangeland management systems

146. Rangelands are inhabited by shepherds and nomadic people who move long distances in search of fodder for their livestock, and who depend on native shrubs and trees for their energy needs. We believe that vast tracts of landscape that present themselves as low-productivity drylands have, in fact, been degraded over the centuries, but do not represent the natural potential of the land. Many examples exist demonstrating that trees can be re-grown successfully on such marginal, degraded land. These restore the productivity of the land, contribute to soil fertility through the continuous input of crop residues (falling litter), and to biodiversity, by providing food and shelter for soil fauna, small birds, and mammals, while at the same time providing income for farmers in the form of fodder, fuel wood, or fruit. These systems can be successfully re-established on degraded and salinized soils (Lamers et al. 2009a, 2009b; Lamers and Khamzina 2008). Self-regenerating legume plants and food legume crops, such as pigeon pea, have proved to be very useful in rehabilitating degraded pastures in the hills. They provide surface cover, improve soil fertility, and supply fuel for the local inhabitants. In recent times, due to dismemberment of the old system of grazing rights, new, small settlement villages have been established in these arid areas. In this context we envisage rangeland and sloping land management programs that combine restoring the common property natural resource base with measures to safeguard these newly upgraded lands, and a reliable and viable seed system for the rangeland species through appropriate institutional and ownership settings.

147. Development of integrated crop–livestock–rangeland management systems around water points in arid range- and pasturelands will improve fodder availability and the productivity of the livestock and reduce degradation around villages. At the same time such measures will rehabilitate the often heavily degraded drylands and rangelands. This is also true for mountainous regions where pastures for livestock abound.

148. The rapidly growing demand for livestock products in the Central Asian countries is opening up opportunities for poverty reduction by obtaining additional income for poor livestock keepers. The main reason that stops these opportunities at present is the lack of access of the rural population to vital services and technologies. With improved access to productive breeds, veterinary care, tools, training, technologies and markets many poor farmers will be able to take a step towards overcoming poverty. Activities within the SLM

program will therefore be complemented with research on livestock management and productivity increase, breeding and veterinary research of livestock as adaptation strategy.

6.3.5 Improving productivity of the mountainous areas

149. Mountainous areas require research on all of the topics above (land management, crop diversification, livestock-rangeland management), but with a stronger focus on controlling soil erosion, which is a predominant problem in sloping lands. Furthermore, it is in the mountainous areas, principally in Tajikistan and Kyrgyzstan – where the predominant part of the population consists of poor farmers –, that these efforts are urgently needed. Thus, working in mountain areas will specifically provide relief to the rural poor.

150. A special research aspect will be on diversifying dwarf teresken shrub communities (Ceratoides, Artemisia species) which cover mountain slopes and high plains and which play a crucial role in soil protection in this fragile environment. They are considered an important feed resource for domestic livestock. These slow-growing shrubs are also harvested for firewood, which opens up gaps in the vegetative cover on the mountain slopes which are then vulnerable to erosion. Finding and introducing alternative sources for energy and livestock feed in these sites will be especially important to protect the land from further erosion damage and desertification.

151. Another important aspect of mountain ecology is the need for restoration of the vegetative cover in the high forested zones of the mountains as well. It is believed that overgrazing over centuries has led to a continuous degradation of the lands, which are not used to their biotic potential. Technical options are available, but the institutional, economic and social constraints for mountain forestry are far from understood. This is certainly one area where an integrated approach, linking natural, economic, and institutional research, can be pursued.

6.3.6 Policies, markets and institutions

6.3.6.1 Economic assessment of technologies

152. The success of efforts by governments, donors, investors, and civil society organizations to address land degradation will depend, among other things, upon the identification and promotion of feasible and profitable agricultural and land management options that are suited to the different agro-ecological environments and farming systems in Central Asia. Unless options are available that guarantee tangible economic benefits within a relatively short period of time, households and communities are unlikely to widely adopt them, except if they are required to do so by well enforced regulations, or are provided with additional incentives to do so (Shiferaw and Holden 2005). Although neither regulatory nor incentive approaches should be ruled out, given the external costs and benefits of land

management practices, such approaches are generally costly to implement and difficult to enforce, and hence may be beyond the capacity of the Central Asian countries to implement widely and well. Poorly implemented regulatory or incentive programs can cause adverse incentives, contributing to rather than ameliorating land degradation problems, and regulatory approaches do not help to reduce poverty. Other constraints to adoption of improved land management, such as lack of farmer awareness of improved technologies, land tenure insecurity or lack of access to credit, may be important if profitable and feasible options exist, but are largely irrelevant to adoption if such options are not available. Given these considerations, assessing the economic feasibility and profitability of sustainable land management innovations in different agro-ecological and socio-economic environments of Central Asia will be an important step in prioritizing investment opportunities to promote SLM and identifying key binding constraints that must be addressed through policy or institutional changes to enable these opportunities to be realized.

153. In areas where profitable opportunities to improve land management are available, but not widely adopted, emphasis will be placed on identifying the most binding constraints limiting their adoption and the most cost effective investments or policy actions to address these constraints. In areas where improved land management options are of marginal expected near term profitability, investigation of the most important market, institutional or policy failures limiting profitability (e.g., external costs and benefits, poor infrastructure, trade policies) will be used to assess the social benefits and costs of alternative interventions to address these (e.g., subsidies or regulations). Where no improved land management approaches can be identified that are already privately profitable, or that could be profitable through feasible and socially beneficial policy interventions, alternative livelihood options (e.g., non-agricultural activities, emigration to less fragile lands) and the means of promoting them should be investigated.

154. This economic analysis will be an input into a broader policy and institutional analysis of options to promote SLM in Central Asia. Several analytical approaches will be utilized (Minimum Data and Household models) to identify optimal SLM technologies, their economic impacts, and resource constraints. The same approaches will be further used in scenario analysis for designing additional interventions to overcome identified constraints.

6.3.6.2 Market and value chain research: linking farmers to input and output markets

155. After independence, the centralized product markets and input supply channels have either largely disappeared in some countries or are still operating in some ways (mainly for cotton and wheat), though in a much less efficient manner. This collapse of the output-input marketing system has added to the disincentives for agricultural production (Spoor 1998). Whereas in South Asia and China local artisans have taken up the challenge of producing the

needed CA and RCT equipment, no such mechanism has been promoted in Central Asia. Herbicide molecules and micronutrient fertilizers are not readily available to the farmers on demand, adversely affecting crop production and possibly also resulting in low quality grains. Farmers generally have to depend on the worn-out and outdated prototypes of Soviet machinery or on the few Indian prototypes recently imported and introduced by ICARDA. Despite the locally available know-how, these prototypes are not replicated in the countries. For the CA equipment, power sprayers, leveling machines and fertilizer nutrients to become available to the farmer for use, an effective institutional network of public-private partnerships for R&D, manufacturers, retailers, servicing agents and financial institutions has to be developed and nurtured to sustain the supply and servicing of the agricultural implements and inputs. For promotion of conservation agriculture in Central Asia, it is required that different stakeholders in the input market supply chain of agricultural inputs must be introduced in the initial years. Assistance is needed in building and reforming market institutions and establishing trade links with a view to reducing transaction costs, mitigating risks, building social capital and redressing missing markets. This would help in diversifying farm production to generate income and meet domestic food demands. Deterioration of storage, processing and distribution facilities add to the problem (Paroda 2007). Given the lack of clearly studied market opportunities, there is no incentive for investment (public or private) in processing industries. The lack of policies and implementing regulations that address trade related aspects of product standards and intellectual property issues has been a constraint both to foreign investments and exports of processed agricultural products. In this regard, achieving food security in the long run will depend not only on improving the productivity of agriculture, but also on re-establishing regional trade and identifying policy options that increase producer incentives to intensify and diversify production. The lack of linkages between farmers and markets is specifically drastic in remote drylands of Central Asia.

156. Presently, there is an acute need for post harvest processing of agricultural produce both for internal markets and for export in order to have additional revenues and improve rural livelihoods. The region produces highly valuable crops (fruits, nuts, vegetables, etc.), but due to poor organization of post-harvest processing and agribusinesses, the quality of storage facilities and processing is low, resulting in losses in production value (Swinnen and Maertens 2007) and little incentives for new crop varieties. The economic efficiency of agriculture could be significantly enhanced if post-harvest management, storage, and processing of crop and livestock products were improved and better oriented towards market opportunities.

157. Market and value chain analyses and risk studies should be conducted on the impact of markets and value chains on diversification of agricultural production, with special emphasis on ‘high value-low volume’ diversification products involving fruits and nuts and

underutilized, aromatic, and medicinal plants, where Central Asia has comparative advantages. Besides, diversified and underutilized crops may provide both a source of revenue for the governments and better opportunities for reducing malnutrition prevalent in some parts of the region. The ability of local producers to compete in both domestic and international markets has important implications for the sustainable use of natural resources and poverty reduction.

6.3.6.3 The role of institutions in promoting SLM

158. The effectiveness of institutions will determine how and whether the desired SLM policies are put into action on the 'ground' since they are the key mediators for policy reforms and other important actions. Dysfunctional institutions on the other hand can seriously undermine any efforts targeted at SLM. By their very nature, institutional reforms are complex and inherently political. Therefore, preliminary multi-stakeholder consultations, coalition building, and promoting champions of change are the pre-requisites for successful institutional transformations using a 'bottom up' approach (Merrey et al. 2007).

159. In the context of Central Asia, research is needed to identify the necessary institutional restructuring to support SLM so that farmers are enabled to generate secure incomes without 'mining' the environmental resources. This also will address the mechanisms for institutional and technical support needed by those farmers new to the industry who are inexperienced in operating individual farm businesses and need help in developing new farm enterprises and applying appropriate SLM technologies.

160. Adequate institutional rights to access rural resources – land water, minerals, trees, and wildlife – are key factors for agricultural development and food security. This necessitates research on different types of land tenure arrangements and the related economies of scale to ensure efficient and sustainable production of agricultural commodities. Farmers can be expected to make long-term investment to conserve their natural resources only if they hold secure and full ownership rights to their land rather than only leasehold rights. However, private land tenure per se will not likely result in SLM unless being accompanied by a comprehensive set of supporting institutional and public policy reforms. Property rights and the need for collective action in the management of common resources have emerged as critical issues. Collective action at the local level is crucial when farmers must come together to manage natural resources. Development of institutional structures and policy reforms to support property rights and the collective management of common natural resources is a priority research area toward SLM.

161. In this regard, there is a need to better understand how rural organizations and private–public–civil society organization (CSO) partnerships can be strengthened and how they can contribute to SLM and enhanced technological and institutional change. Such research will be carried out with respect to identifying the effects of gender, and will be

sensitive to the implications of changing forward and backward linkages along the entire product supply chain (including pre-, on- and post-farm elements that involve input supplies, primary producers, processors, and marketing entities). The increasing level of organization allows for the better distribution of new knowledge and technologies to the individual farmer. Institutional analysis is needed to either assign new roles for existing institutions or establish new institutions to enhance adoption of SLM and to combat land degradation.

6.3.6.4 Policy dimensions of land degradation in Central Asia

162. In Central Asia, more than anywhere else, land degradation and rural poverty are driven not merely by technical failings, but more so by institutional and policy failings. Numerous institutional and policy reforms, either adopting liberal approaches or embracing gradual and conservative principles, have been implemented in the countries of the region after gaining independence to overcome the Soviet heritage of a centralized command economy (Asad and Banerji 2000). However, irrespective of differences in approaches, in most instances these reforms have not led to SLM. Arguably, one reason for these failures is that these reforms had never been formulated and implemented with SLM as one of the top priorities, but rather were either largely over-shadowed by concerns over food security and social stability or conducted in a piecemeal and opportunistic manner. In most cases, agriculture was considered as a conduit for extracting resources for industrial growth.

163. Policy reforms do not start haphazardly, but are always embedded in a socio-economic and policy context with a culture, history, technical environment, and vested interests that shape the margin for change (Merrey et al. 2007). In addition to these, globalization of markets that will continue growing and its impact has already become an important factor in the region. For this reason, the policy research should be able to properly assess and diagnose this interplay of factors and suggest comprehensive approaches that would promote SLM while better satisfying various national concerns and addressing the challenges of globalization.

164. The extent of policy influence and the effectiveness of existing policies on land degradation are presently not adequately quantified. Without rigorous assessment of the consequences and implication of alternative policies, their application may lead to unacceptable outcomes on poverty reduction and land degradation. For example, investigation of the political and institutional feasibility of incentive mechanisms, such as payments for ecosystem services, notably water pricing, as well as the costs of implementation and distributional impacts, should be carried out. This needs a hierarchical diagnostic approach that takes into account that overcoming certain constraints or failures is a pre-requisite for other factors to be relevant.

165. Another important policy dimension with respect to climate change is the promotion of carbon trade in the region. As Robinson and Engel (2008) write: "*All Central Asian*

republics have ratified the UNFCCC and all except Kazakhstan have ratified the Kyoto Protocol. The latter introduces binding emissions reductions targets for 'Annex 1' countries and also introduces flexible mechanisms for emissions reductions through carbon trading and investments in greenhouse gas reduction in other countries. All Central Asian countries which have ratified the protocol are 'Annex II' countries, which means that they do not have binding targets for emissions reductions; Kazakhstan is negotiating to join the protocol as an Annex 1 country. Of the flexible mechanisms, the Clean Development Mechanism (CDM) is the most relevant to Central Asia. The CDM allows an Annex 1 country with an emissions-reduction target to implement emission-reduction projects in developing (Annex II) countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one ton of CO2, which can be counted towards meeting Kyoto targets. Participating Annex II countries must set up a Designated National Authority (DNA) to manage this process. Projects must qualify through a rigorous and public registration and issuance process which imposes heavy administrative costs on host countries. At present of the Central Asian countries only Kyrgyzstan and Uzbekistan have notified the UNFCCC secretariat about its DNA contact point. These DNAs are not fully functional and are heavily dependant on donor support for capacity building. .... One of the major barriers is finding investors for these projects. ... CDM projects ...in countries such as India, China, Brazil and Mexico ... offer high GHG emission reduction potential for low investment, however broader development impact (in terms of income, employment or environmental impact) is often minimal. This is because carbon finance revenues by themselves are rarely sufficient to make the underlying projects economically feasible. ... Of land use projects under the CDM, only forestry projects are permitted at present, because accompanying modalities and procedures for baseline calculation and monitoring are lacking for other types of land use projects. However there are other possibilities to generate saleable emissions reduction units through land management activities. The World Bank BioCarbon Fund (amongst others) purchases alternative saleable units known as Verifiable Emissions Reduction units (VERs) which may come from a range of land management projects. Whilst these units cannot be traded directly through the CDM the BioCarbon Fund may purchase them for sale through other mechanisms." As outlined above, there are new methodologies and mechanisms under development.

6.3.7 Capacity building and knowledge dissemination

6.3.7.1 Academic capacity building

166. Several autonomous agricultural universities and academies have the combined mandate for agricultural education and research in Central Asia. However, these institutions struggle with lacking funds for young scientists, outdated research facilities and materials and little knowledge of computer programs. Furthermore, the research reporting and data analysis

has shown to seldom meet international requirements for publication. The quality of training in these institutions can be significantly improved through post-graduate fellowship programs in advanced institutions and CGIAR Centers. Such an approach can help ease the acute shortage of well-trained, young researchers. Therefore, a sufficient number of scholarships will be provided to enable these young professionals from Central Asia to carry out research while providing on-the-job training. We will team up with internationally renowned colleges and universities in the region and abroad to provide adequate supervision.

6.3.7.2 Technical capacity building, training and extension

167. Involvement of the private sector, especially outsourcing activities to local NGOs, private entrepreneurs, and input and service providers, can partly compensate for the current weak extension systems. It will also create different channels of implementation of the SLM aims, which as separate pillars of the civil society will strengthen and support the activities from the basis.

6.3.7.3 Knowledge and its dissemination

168. Achieving sustainability of the innovations that may result from the work in this program requires a judicious strategy of disseminating technologies to farmers as well as to policy makers. The latter need to ensure that they create an ‘enabling policy environment’, so that the innovations can take effect. One objective is therefore to effectively communicate scientific project results with a policy relevance to policy and decision makers.

169. The dissemination and communication strategy of this program would therefore encompass both distributing scientific information as well as providing decision makers with the relevant policy information they need. This will be achieved through the organization of workshops, training and information sessions, field visits, and media work, as well as through the production and publication of information materials (printed and electronic). We will, for example, develop a special series of two-page, short communications (‘Perspectives in Agriculture’) as summaries of important, practice relevant, project results delivered in several languages (Russian, English, and local languages where pertinent) to be delivered to the key institutions. These will also be published in an electronic version for dissemination through the internet.

170. In the time of the increasing importance of the internet, the web-appearance of the project program is an essential platform for providing information and increasing awareness about ongoing SLM activities. For this purpose, all research deliverables as well as information on trainings, workshops and publications will be visualized and supported by relevant documents to be accessible to interested partners, donors and scientists.

7 Implementation arrangements

7.1 *Partners*

171. In Central Asia, agricultural research is carried out by a number of research institutions and their associated out-reach research stations under the Ministries of Agriculture and Nature Protection. In addition to these there are the autonomous agricultural universities and several academies which also have the combined mandate for agricultural education, research, and extension. The region has more than a hundred agricultural research institutions conducting research activities on important aspects of agriculture. There is an acute shortage of well trained, young researchers. Therefore, many superannuated scientists have to be redeployed to meet the obligations of the public sector institutions. The role of the NARS in project implementation is crucial. International organizations, such as ICARDA and the CGIAR-PFU for Central Asia, can only play a seminal role; the bulk of the implementation will be with the national partners, that is, the research institutions and universities. The private sector involvement is rather minimal and it will be crucial to promoting public–private partnerships.

7.2 *Beneficiaries*

172. The stakeholders of the sustainable land management research (SLMR) can be categorized as (1) institutional stakeholders, such as government agencies, etc.; (2) non-governmental entities involved in providing goods and services (private sector entrepreneurs, custom service providers, input suppliers, etc.), social intermediation, farmers and water users associations; (3) end-users or beneficiaries of the projects and activities included in the national program; and (4) donors and specialized external agencies, as providers of crucial investment or technical assistance support and advisory services. In SLMR, people necessarily have to be the ‘agents of change’ and not just the beneficiaries of goods and services. The farming community, including the water users associations, private sector small entrepreneurs, and input suppliers will actively benefit from the research.

7.3 *Facilitation role of CGIAR-PFU and ICARDA*

173. The CGIAR Collaborative Research Program for CAC was initiated in 1998 when the CGIAR allocated US$ 2 million as the initial funding for the program. Eight CGIAR Centers are currently participating in the program. These include Bioversity International, CIMMYT, CIP, ICARDA, ICRISAT, IFPRI, ILRI, and IWMI. In addition, three other members, AVRDC-World Vegetable Center, the International Center for Biosaline Agriculture (ICBA) and Michigan State University (MSU), have joined as members of the Consortium. Since the

establishment of the collaborative program, there have been extensive consultations between CGIAR Centers and NARS to identify and prioritize thematic research options.

174. CACILM's multi-country Secretariat has established formal strategic partnerships in SLMR with national agricultural research systems in Central Asia, major UN Organizations (FAO, UNDP, etc.) as well as ICARDA, representing through the CGIAR-PFU, all 15 CGIAR institutions. The CGIAR can be extremely functional to the SLMR implementation process, by playing the role of 'honest broker' between all participants, by providing sound scientific input, as well as its ten years of expertise gained in the CAC region. The policy makers of the CAC region have recognized the value of the collaborative research program and are committed to strengthening research for the development of sustainable agriculture.

175. Central Asia is not only a relatively heterogeneous region in terms of soils, landscapes, climate, and vegetation, but also in terms of policy frameworks, institutional performance, research networks, and their research capacities. ICARDA convenes the CGIAR-CAC consortium housed in its Regional Office in Tashkent, but engages also in strong inter-center linkages. These include a joint program on major cereals (wheat and barley) with CIMMYT, active linkages with ICRISAT on legumes, and CIP on potato. ICARDA's activities go well beyond simple genetic enhancement of crops and livestock, and include sustainable management of natural resources. The PFU of the consortium membership includes eight CGIAR centers and three advanced research institutions; it has strong ties to all national NARS and has been active in the region for ten years. Thus, through the PFU ICARDA can capitalize on its extended partnerships.

176. The pathway through which this SLM will achieve impact will reflect the heterogeneity outlined above. It emphasizes farm-level participatory needs assessment (involving all stakeholders) and networking in the process of technology generation and its refinement with the NARS partners. It includes private entrepreneurs, input suppliers, CGIAR Centers, and national agricultural research institutions (ARIs). It will also provide information exchange on 'best practices' and the land degradation assessments (SLM-Information System, SLM-IS, component) and on constraints of human resources vis-à-vis needs for capacity building for sustainable land management research (through the SLM-Capacity Building, SLM-CB, component). The linkages and mechanisms existing at PFU Tashkent will be crucial assets in the process of technology generation, validation, and dissemination. The pathway also indicates that the involvement of the private sector, especially private entrepreneurs and input and service providers, can partly compensate for the weak extension systems.

8 Conclusions and outlook

177. The ever-increasing human and livestock populations and competing demands for land and water from different sectors of the national economies of Central Asia require that the factor productivity of the inputs be improved to produce additional food and fodders. Pressure on land and water resources leads to inappropriate land use plans in marginal areas. New, inexperienced farmers, inappropriate agronomic and crop management technologies, and declining irrigation water quality aggravate land and water degradation.

178. To achieve the SLM objectives, the agro-ecological perspectives of land management (bio-climatic, soilscape, and technical innovations) need to be combined with socio-economic perspectives to result in sustainable livelihoods, while preserving the multi-functional role of the drylands' ecosystems. For the Central Asian countries undergoing transition, the first priority is to increase agricultural productivity and focus on the pathways out of poverty, especially by increasing the production of high value products as a way of focusing on alternative sustainable livelihoods vis-à-vis sustainable land management (SLM). It is believed that resource conserving technologies, which include a wide range of practices, can serve as regional strategies for improved livelihoods and sustainable development.

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Figures

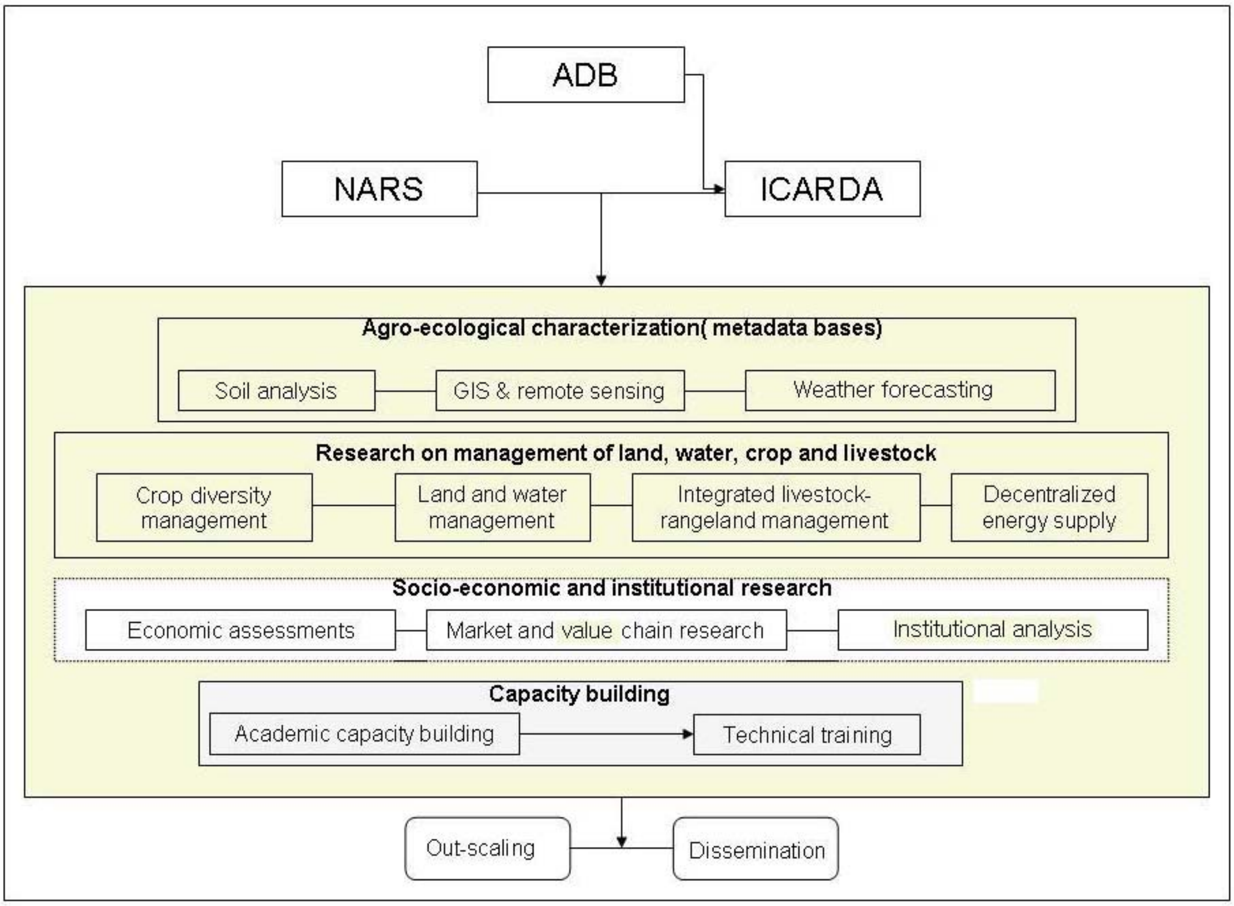

Figure 1: Outline of the elements of the research framework ('Research Prospectus') for sustainable land management (SLM) research in Central Asia

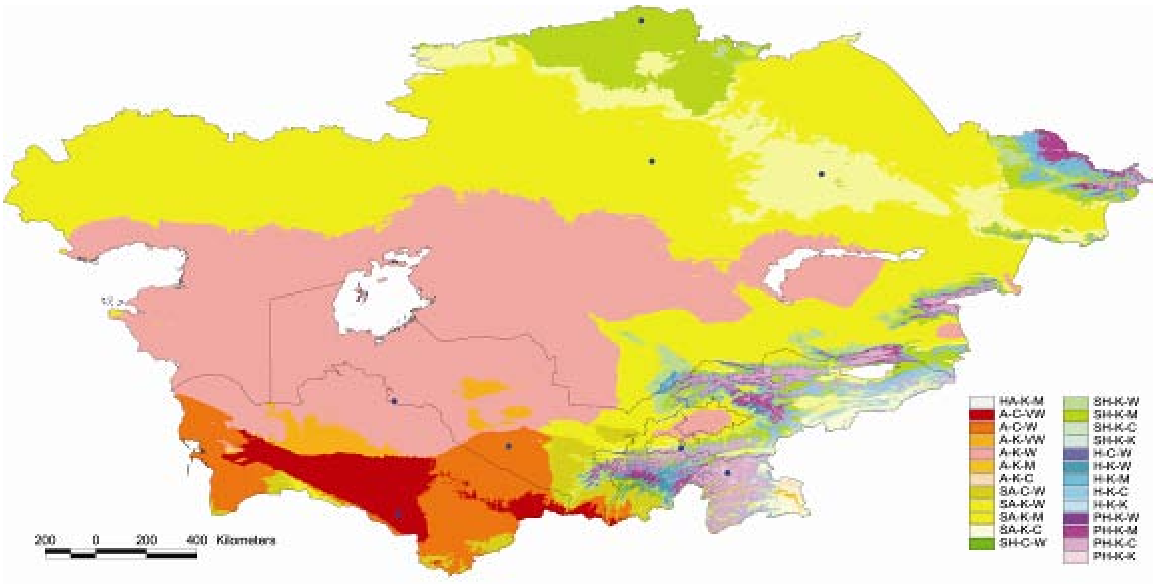

Figure 2: Agroclimatic zones of Central Asia (source: de Pauw 2007)

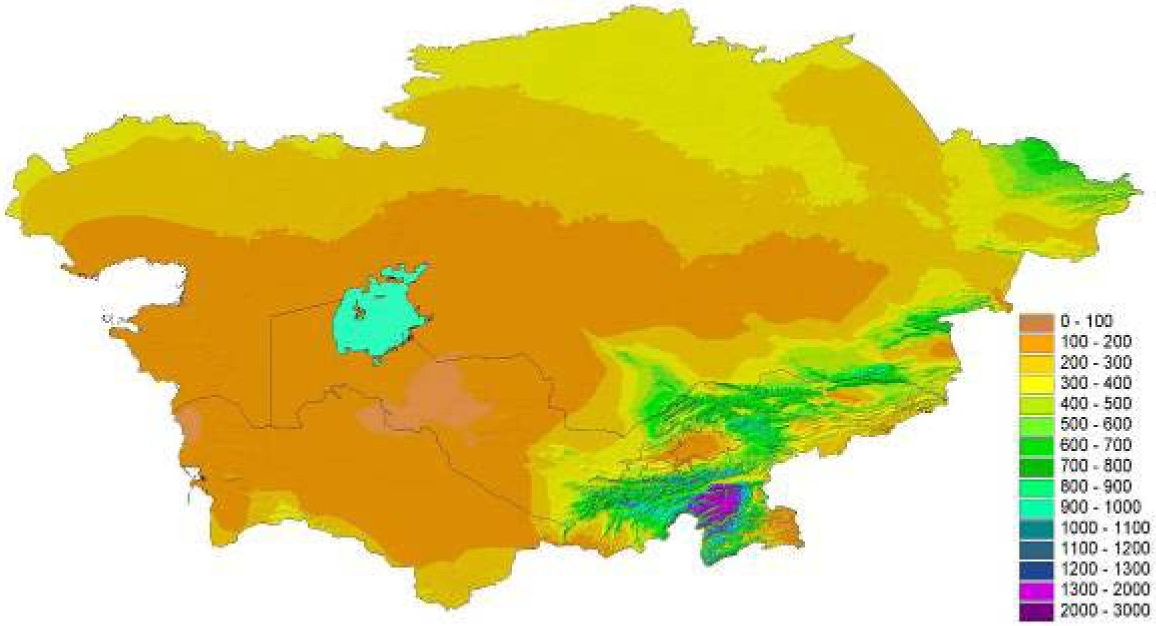

Figure 3: Mean annual precipitation (source: de Pauw 2007)

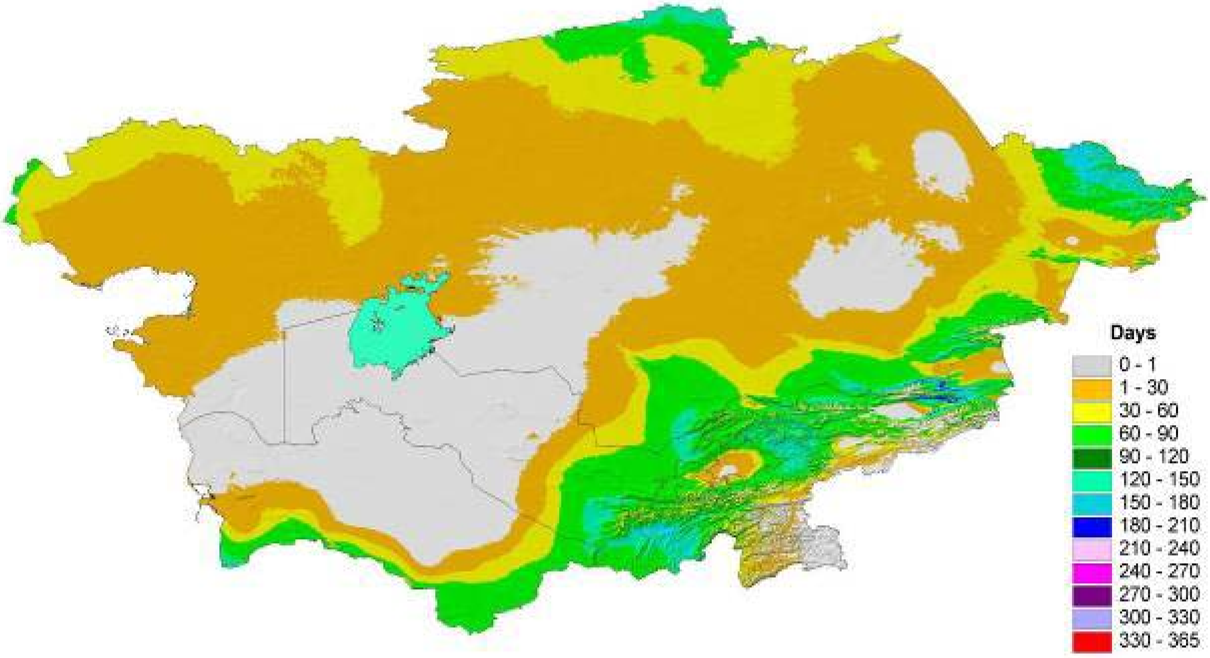

Figure 4: Length of growing periods in Central Asia (source: de Pauw 2007)

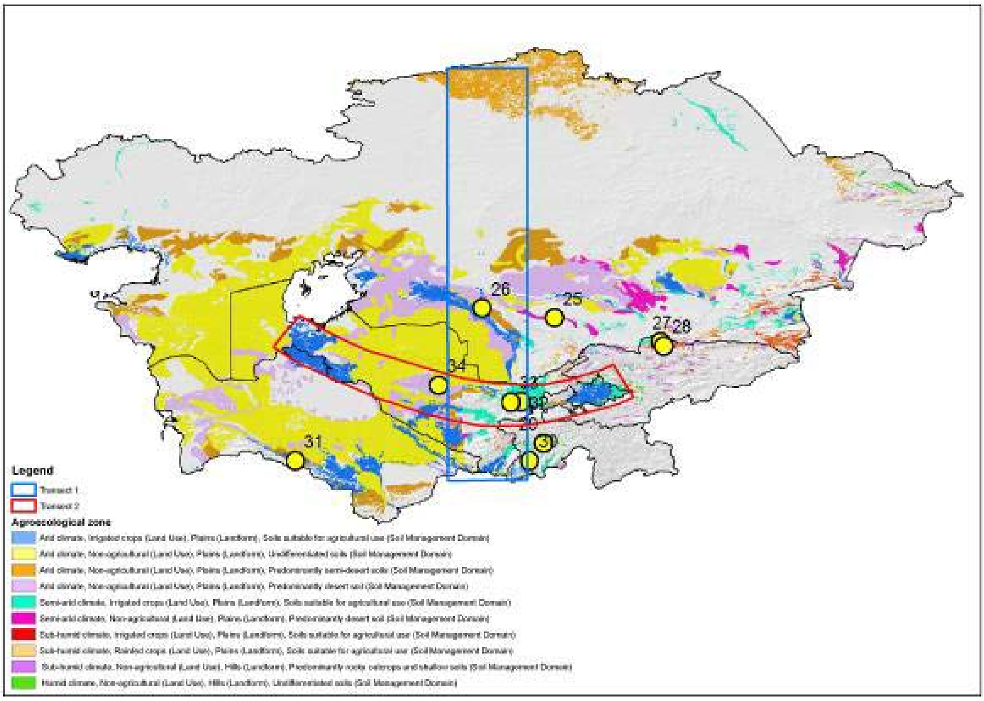

Figure 5: Two perpendicular transects (marked red and blue) allow the inclusion of all major ecosystem areas relevant for SLM research in Central Asia. Adequate benchmark sites will be identified within these transects (graph: O.Tsay, personal communications).

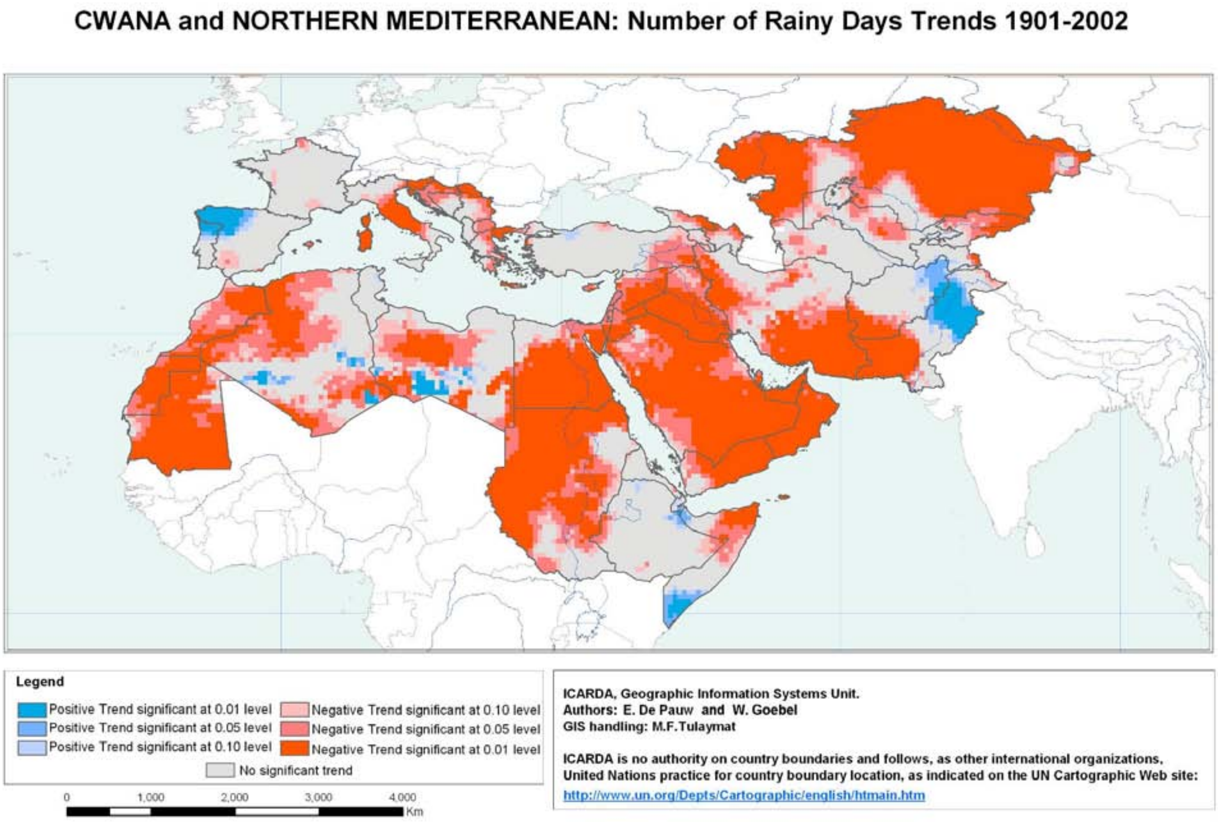

Figure 6: The observed trend of decreasing number of rainy days in CWANA

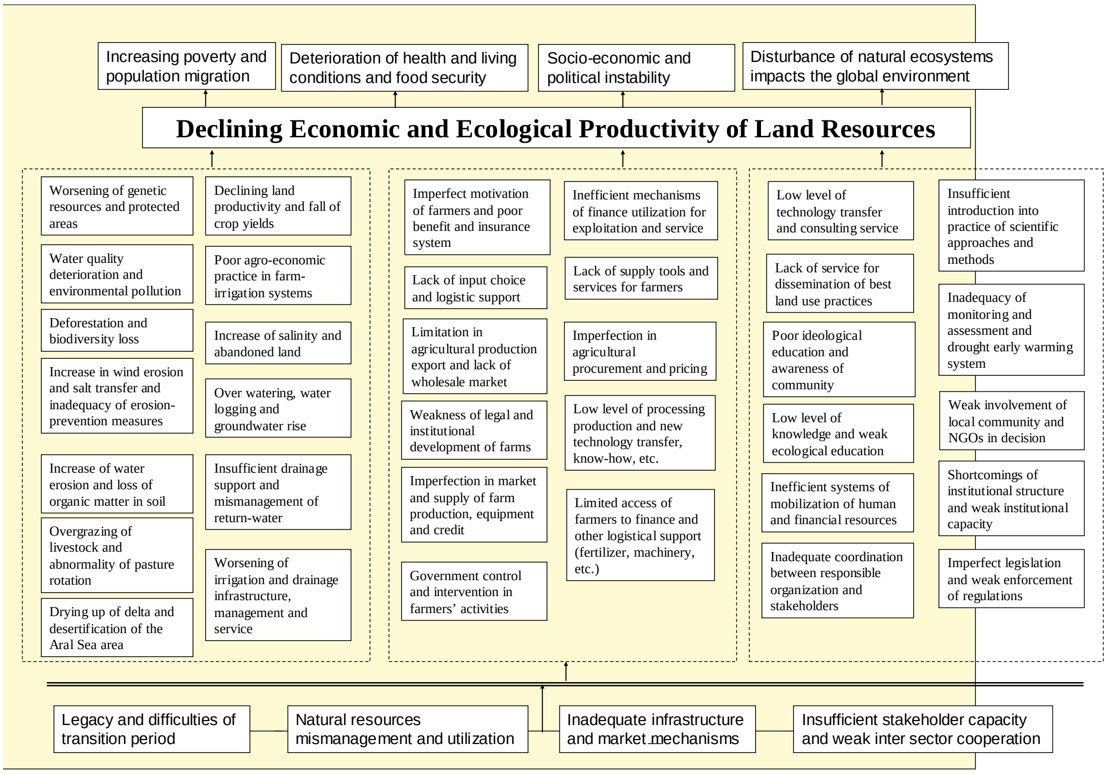

Figure 7: Land degradation 'Problem Tree' and its influence on human wellbeing

Tables

Table 1: Land use statistics in Central Asia (million hectares) (source: FAO 2006)

Country	Total Land Area	Arable Lands		
		Rainfed	Irrigated	Pasture and Rangelands
Kazakhstan	269.970	18.994	2.312	185.098
Kyrgyzstan	19.180	0.238	1.072	9.365
Tajikistan	13.996	0.208	0.722	3.198
Turkmenistan	46.993	0.400	1.800	30.700
Uzbekistan	42.540	0.419	4.281	22.219
Total	392.679	20.259	10.187	250.580

Table 2: Agroclimatic zones derived from the underlying data (source: de Pauw 2007)

Agroclimatic Zone	Description	Aridity index[1]	Temp. range coldest month	Temp. range warmest month	% of total
SA-K-W	Semi-arid, cold winter, warm summer	0.2 - 0.5	<= 0°C	20° - 30°C	37.9
A-K-W	Arid, cold winter, warm summer	0.03 - 0.2	<= 0°C	20° - 30°C	30.8
SA-K-M	Semi-arid, cold winter,	0.2 - 0.5	<= 0°C	10° - 20°C	6.6
SH-K-M	Sub-humid, cold winter,	0.5 - 0.75	<= 0°C	10° - 20°C	5.9
A-C-W	Arid, cool winter, warm summer	0.03 - 0.2	0° - 10°C	20° - 30°C	4.9
A-C-VW	Arid, cool winter, very warm summer	0.03 - 0.2	0° - 10°C	> 30°C	2.9
PH-K-C	Per-humid, cold winter, cool summer	> 1	<= 0°C	0° - 10°C	2.0
H-K-M	Humid, cold winter, mild summer	0.75 - 1	<= 0°C	10° - 20°C	1.6
SA-C-W	Semi-arid, cool winter, warm summer	0.2 - 0.5	0° - 10°C	20° - 30°C	1.5
SH-K-W	Sub-humid, cold winter, warm summer	0.5 - 0.75	<= 0°C	20° - 30°C	1.4
A-K-VW	Arid, cold winter, very warm summer	0.03 - 0.2	<= 0°C	> 30°C	1.2
PH-K-M	Per-humid, cold winter,	> 1	<= 0°C	10° - 20°C	1.2
SH-K-C	Sub-humid, cold winter, cool summer	0.5 - 0.75	<= 0°C	0° - 10°C	0.5
SA-K-C	Semi-arid, cold winter, cool summer	0.2 - 0.5	<= 0°C	0° - 10°C	0.5
H-K-C	Humid, cold winter, cool summer	0.75 - 1	<= 0°C	0° - 10°C	0.5
H-K-W	Humid, cold winter, warm summer	0.75 - 1	<= 0°C	20° - 30°C	0.2
SH-C-W	Sub-humid, cold winter, warm summer	0.5 - 0.75	0° - 10°C	20° - 30°C	0.1
A-K-M	Arid, cold winter, mild summer	0.03 - 0.2	<= 0°C	10° - 20°C	0.1
PH-K-K	Per-humid, cold winter, cold summer	> 1	<= 0°C	<= 0°C	0.1
PH-K-W	Per-humid, cold winter, warm summer	> 1	<= 0°C	20° - 30°C	0.0
A-K-C	Arid, cold winter, cool summer	0.03 - 0.2	<= 0°C	0° - 10°C	0.0

The ratio of the mean annual precipitation over the mean annual potential evapotranspiration

Table 3: Summary of precipitation levels in Central Asia (source: de Pauw 2007).

Precipitation class (mm)	% of Central Asia	Mean (mm)	Standard deviation (mm)
0-100	1.19	266	160
100-200	38.28		
200-300	31.08		
300-400	18.73		
400-500	3.93		
500-600	2.60		
600-800	2.62		
800-1000	0.89		
1000-1500	0.53		
1500-2000	0.14		

Table 4: Acreage of problematic lands in Central Asia (million hectares) (source: Bot et al. 2000)

Country	Salinity	Sodicity	Shallowness	Erosion
Kazakhstan	21.5	107.1	38.6	7.8
Kyrgyzstan	0.1	-	10.7	5.6
Tajikistan	0.7	-	6.8	3.7
Turkmenistan	7.3	1.7	3.5	0.7
Uzbekistan	6.3	4.6	3.9	1.3

Table 5: Relative research priorities for sustainable land management (SLM) research in Central Asia

Agri-Production systems	National food security	House-hold food security /poverty alleviation	Sustainability of NRM and environmental quality	Climate change and water avail-ability and productivity	Small farm mechanization, production costs	Diversification, intensification and product development	Germplasm diversity (crops and livestock)	Institutional networks
Irrigated	***	**	***	**	***	***	**	***
Rainfed	**	***	***	***	**	**	***	***
Rangelands	***	***	***	***	**	***	*	***
Mountains and foot hills	***	***	***	***	*	***	***	***

*** high priority; ** medium priority; * low priority; NRM: Natural resource management

Table 6: Recorded climate change in Central Asia by country (source: Initial National Communications to the UNFCCC).

Time Periods	Kyrgyzstan	Kazakhstan	Uzbekistan	Tajikistan	Turkmenistan
	1900-2000	1894-1997	1900-2000	1961-1990	1931-1995
ΔAnnual Temp.°C	+1.6	+1.3	Significant but not quantified	+0.7- +1.2 valleys +0.1- +0.7 Hills	+0.18
Δ Winter Temp. °C	+2.6	+1.8	-	-	+0.1
Δ Summer Temp. °C	+1.2	+0.8	-	-	+0.2
Δ Rainfall, mm	+23mm overall but highly variable between stations	-17 (mostly in winter, small increases in other seasons)	Significant increase in valleys, no increase in mountains and foothills.	Variable: increases in some areas, decreases in others	+12mm overall, mostly in winter

Table 7: Key research questions and activities for promoting sustainable land management

Priority areas/Production systems	**Key Research Questions**	**Objectives**	**Activities**
A. Agro-ecological characterization of production systems for better understanding of dryland degradation and its dynamics to enable adoption of appropriate rehabilitation measures. (Over-arching Issues)	A1. How can research systems be made more cost effective for the process of technology generation and information dissemination in the different agro-ecologies and production systems found in Central Asia?	a. Develop soil maps following a unified soil taxonomic system of soil classification. b. Develop meta-database for development of land degradation in different agro-ecological maps to assess the technology needs on a sub-regional basis.	i. Establish sentinel 'Benchmark Soil Series' following widely used (USDA/FAO) soil classification system for dynamic assessments of the land and environmental quality under different management options. Establish a modern regional Soils Laboratory modeled on the soil laboratory of ICRAF. ii. Develop agro-ecological region/sub-region maps and identify the NRM constraints of each production system. Establish a regional Remote Sensing and GIS laboratory to digitize bio-climate, soil-scape, water resources, and available socio-economic infra-structure database to facilitate integration of biophysical and socio-economic processes driving land degradation. iii. Use of remote sensing and GIS tools for dynamic assessments of land degradation under different land uses. iv. Establish a Medium Range Weather Forecasting laboratory to link farm advisory services to dynamic weather situations. v. Assess carbon sequestration potential of production systems in different agro-eco-regions to mitigate climate changes.
	A2. What attributes of degraded dry lands contribute to predicting thresholds and resilience of soils in different toposequences and agro-ecologies of Central Asia?	a. Develop an empirical understanding of the thresholds and resilience of the drylands under different land uses in different toposequences.	i. Study the threshold tolerance of benchmark soil series to degradation under different land uses in specific toposequences. Identify measures to make soils more resilient
	A3. What are the distinguishing livelihood	a. Develop information on the livelihoods and human	i. Map the livelihood of the people who depend on natural resources at

	features of people living in different agro-ecologies?	development perspectives for different agro-ecologies/production systems.	‘Sentinel sites’.
B. Genetic Enhancement of cultivars for improved crop productivity and seed systems	B1. How can availability of food grains and fodders for livestock be improved in Central Asia?	a. Develop dual purpose (grain and straws) wheat cultivars for improved tolerance/resistance to biotic and abiotic stresses for the RCT platforms. b. Develop self regenerating legumes to reduce erosion hazards on sloping arable lands. c. Develop seed systems for cotton, wheat and other diversification crops.	i. Breed for dual purpose wheat/Triticale (for grain and green fodder), for RCT platforms, with resistance to Ug99 and other biotic and abiotic stresses and improved grain quality for bread making. ii. Evaluate grain legumes and fodder crops for cold, heat and moisture stresses to promote their cultivation in RCT platforms to improve soil fertility and enhance fodder availability vis-à-vis productivity of livestock. iii. Setup national seed industry association; harmonize seed laws, regulatory frameworks, common methodologies for testing and varietal release. Quarantine and germplasm movement policies.
C. Land and water management for irrigated and rainfed areas	C1. How can factor productivity of the intensive cotton–wheat systems be improved to enhance farm-gate incomes and soil health?	a. Develop innovative land and crop management practices for the cotton–wheat systems for conservation agriculture platforms. b. Dynamic assessments of water availability and allocations to optimize profitability and productivity.	i. Promote laser assisted precision land leveling for improving the performance of other resource conserving technologies ii. Develop and fine-tune new multi-crop planter prototypes to promote conservation agriculture through custom services. iii. Develop innovative agronomic and crop management practices (including for the weed management) to adapt climate changes in RCT/CA platforms for the cotton–wheat system. iv. Develop protocols for managing demands and supplies for irrigation water at different scales (canal command and river basins).

	C2. Can diversification improve the livelihoods and ecosystem services of the irrigated drylands?	a. Evaluate the potential for diversification of cotton–wheat systems with high value legumes and vegetable and tuber crops	i. Develop innovative inter-cropping systems to promote diversification of cotton and wheat based systems with maize, grain legumes, oilseeds, vegetables, and potato. ii. Develop new niches for intensification and diversification of the irrigated agri-horti- production systems (fruit crops, cash crops, indigo) to improve the livelihoods of local people. iii. Develop weed management practices in cropping system perspectives for the irrigated, rainfed and pasture lands.
	C3. How can water-logging and secondary salinization problems be overcome to sustain the irrigated production systems?	a. Develop technologies for conjunctive use of multi-quality waters for favorable salt and water balances in cotton–wheat systems.	i. Develop irrigation water quality guidelines for use of low quality surface and ground waters for major cropping systems under different agro-climatic conditions. ii. Control saline seeps and rehabilitate the already degraded saline/sodic lands using bio-remediation methods.
	C4. Can resource conserving technologies (RCTs) contribute to improved soil health and livelihoods for sustainable development?	a. Understanding the development pathways that improve success of RCTs.	i. Identify and quantify social, economic, and cost reducing and yield enhancing benefits of RCTs. ii. Target the technologies using remote sensing and GIS tools for up-scaling and out-scaling RCTs. iii. Estimate adoption path with and without enabling policy options.
	C5. How can dryland ecosystems meet the energy needs of the rural poor and their livestock to reduce land degradation?	a. Develop cost effective technologies for harnessing renewable energy in dryland ecosystems.	i. Assess food, fodder, and energy needs of farms located in fragile areas of different agro-eco-regions to prevent out- migration. ii. Harness the potential of renewable energy sources (wind and solar energy) and of free flowing, small, perennial water streams, irrigation, and drainage channels by using micro-hydro-turbines for energy generation.
	C.6 Which strategy can be used to enhance the productivity of the rainfed	a. Develop technical options to improve soil fertility and reduce soil moisture stress	i. Adopt water harvesting/storage technologies for supplemental irrigation in rainfed regions and water harvesting for rangeland improvement.

	arable lands constrained by low temperature and soil moisture stresses?	through supplemental irrigation.	ii. Introduce crops tolerant to cold/frost and soil moisture stresses into the cropping system. iii. Introduce legumes, cereals (maize, Triticale), oilseeds, forage crops, and grasses to reduce summer fallows and potentially substitute uneconomic crops in the rainfed areas. iv. Research on soil carbon storage in dry lands
D. Integrated livestock-rangeland management systems	D1. How can the productivity of the vast acreage of the range and pasture lands be improved?	a. Evaluate the potential of watering points in range and pasture lands to grow Triticale, barley and dual purpose wheat to improve fodder supplies, to reduce livestock mortality, and improve animal health.	i. Develop and introduce self regenerating legumes to improve fertility of the range and pasture lands to reduce erosion. ii. Introduce new germplasm (forage grass/trees/shrubs) tolerant to heat, cold, and water stresses and develop range management practices for enhancing fodder supplies in lean periods iii. Develop innovative re-seeding/planting techniques for rehabilitation of rangelands using micro-catchment water harvesting technology. iv. Low-cost technologies for improving the productivity of livestock and appropriate options for rangeland management and rehabilitation
	D2. What approaches in range and pasture land management can receive active legal and technological support to fill the institutional vacuum?	a. Resolve disputes between herders from different communities to enable the adoption of community-based pasture management practices in areas with limited pasture capacity.	i. Dynamic assessment of pasturelands for their biomass potential (remote sensing and optical sensors – NDVI). Establish mechanisms for sharing and exchange of information
F. Improving productivity of the mountainous areas	F1. How can soil erosion be reduced up-stream to prevent land degradation in down stream areas?	a. Develop tree─crop─livestock management options on CA platforms in watershed approaches.	i. Develop conservation agriculture practices to reduce irrigation-induced erosion through controlled traffic up-down cultivation on sloping lands (up to 10-12% slopes) ii. Develop snow cache technologies for improving soil availability for

			biomass production (food, fodder, and fuels). iii. Develop nutrient, water, and crop management practices (potato/vegetable and tree crops) for rationale use of the sloping/rolling toposequences.
	F2. Do Central Asian countries have a comparative advantage for livestock and high value fruit/nuts production systems in sloping and mountainous areas?	b. Evaluate the benefits of livestock and fruit tree based production systems in sloping landscapes.	i. Integrate tree–crop–livestock based systems in watershed approaches to influence food web and critical flows of energy and nutrients through the systems to reduce wind and water erosion problems and enhance the productivity of the agro-ecosystems. ii. Develop value added products and link people to markets
G. Policies, markets and institutions	G1.What policy, market, and institutional (PMI) failures contribute to land degradation in Central Asia?	a. Assess the effectiveness of existing PMI infrastructure and draw lessons learned in the context of sustainable land management. b. Assess the cost of land degradation and its impact on livelihoods. c. Build capacity for PMI research to improve the understanding of PMI forces to mitigate land degradation.	i. Assess the private and social costs of PMI failures. ii. Assess and quantify the cost of land degradation and its impact on livelihoods under different agro-ecologies. iii. Strengthen the capacity of the NARS for PMI research.
	G2. What contributes to enabling PMI environment to promote sustainable land management in Central Asia?	a. Identify policy options that favor sustainable management of land resources. b. Promote policies, institutions and market mechanisms that enable sustainable land management and improve the	i. Identify win-win PMI options for different agro-ecozones. ii. Quantify economic and environmental trade-offs associated with alternative policy options and value environmental benefits/externalities. iii. Study policies that undermine investments in RCTs and pathways that improve the adoption rates of the RCTs.

		livelihoods	iv. Promote win-win PMI options in the region to overcome policy, market, and institutional dynamics that aggravate land degradation. v. Strengthen the capacity of NARS in policy advocacy.
	G3. Are technical innovations for sustainable land management economically feasible?	a. Promote feasible and profitable agricultural and land management options.	i. Evaluate the comparative advantages of SLM technology options in different production systems to prioritize investments and policy actions.
	G4. How can agricultural commodity value chains contribute to sustainable land management in the region?	a. Evaluate the impact of existing value chains on farmers' profitability. b. Promote value chains that improve farmers' profitability and, hence, investment capacities.	i. Value chain analysis of traditional and underutilized diversified crops. ii. Promotion of high value underutilized and diversified crops.
H. Capacity building and knowledge dissemination (overarching)	H1.How can technology generation and dissemination systems be truly grounded in the biophysical and socio-economic contexts of the intended landed users?	a. Cross-fertilize the process of technology generation and dissemination in farmer-led participatory research approaches.	i. Re-orient agricultural research and technology dissemination processes in NARS to enhance the role of farmers in decision making. ii. Impart post-graduate training to young, national scientists in CGIAR centers. iii. Reform extension services to facilitate technology transfers. iv. Promote public–private partnerships to improve service infra-structure and introduce custom services. v. Organize 'Farm Fests' and traveling seminars to promote innovative technologies.

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