

Agriculture in Central Asia: Research for Development

Editors

John Ryan, Paul Vlek and Raj Paroda



International Center for Agricultural Research
in the Dry Areas



Center for Development Research
(ZEF)

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Foreword

Central Asia, the corridor connecting Europe and the Far East, is replete with the history of human endeavours. It has seen civilizations wax and wane and witnessed countless cycles of turmoil and peace throughout the ages. The names of cities such as Samarkand and Bukhara evoke images of rich history of a bygone era. The "Silk Road" brings to mind great adventures of travellers and explorers.

The ethnic mix in Central Asia today reflects that evolution and change have been constant features of this ancient land. After decades as part of the Soviet Union, Central Asia recently experienced another major economic and social change as the old State economy is transforming into a system based on free enterprise.

The immediate consequences of the disintegration of the Soviet era were the birth of new and independent nations. The sudden change in the economic structure of the five emerging countries of Central Asia--Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan--impacted all aspects of agriculture. Markets and administrative structures were disrupted. Agricultural output of crops and livestock were reduced.

These changes in agriculture in the region drew intensified interest of the international community. The international agricultural research centers, sponsored by the Consultative Group on International Agricultural Research (CGIAR), made a major effort in addressing the emerging agricultural problems in Central Asia. The effort, spearheaded by the International Center for Agricultural Research in the Dry Areas (ICARDA), led to formation of a Consortium of CGIAR centers in 1997 that developed a Collaborative Program for Sustainable Agricultural Development in Central Asia and the Caucasus, which started operating in 1998. Currently, 10 CGIAR centers are members of the Consortium.

To address the problems of agriculture in Central Asia, ICARDA and the Center for Development Research (ZEF) Bonn, Germany, jointly sponsored a symposium on "Agricultural Development in Central Asia" at the American Society of Agronomy, Soil Science Society of Agronomy, Soil Science Society of America, and Crop Science Society of America Annual Meeting in Indianapolis on 10-14 November 2002.

The presentations at the symposium encompassed a range of issues from the economic and structural to the biophysical aspects of agriculture, including soil resources, water management, cereal and legume crops, livestock and rangeland, biodiversity, conservation tillage, and greenhouse gas fluxes. Together they make up the present volume and present a fairly vivid picture of agriculture in Central Asia. Given the shortage of published information on agriculture in the five

republics, especially in English, this volume should serve as a reference source of information for future research and development efforts.

It is hoped that the volume will be of interest not only to researchers and educators, but also to anyone with an interest in the region. There are lessons to be learned for the whole world. As such, it may promote an understanding of the differences between the republics in their resources and management systems, and help in securing support for future agricultural development to improve the livelihoods of the people of Central Asia.



Prof. Dr Adel El-Beltagy
Director General
ICARDA

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Introduction

The region of Central Asia and the Caucasus (CAC), encompassing Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan in Central Asia and Armenia, Azerbaijan and Georgia in the Caucasus, has undergone tremendous economic and social change following the dissolution of the former Soviet Union. *Economies have shrunk, incomes have fallen, poverty has increased and food security is compromised.* Gross national income per capita has declined by an average of 40% between 1991 and 1999, compared with an average increase in other low and middle income countries over the same period. Six of the CAC countries (Armenia, Azerbaijan, Georgia, Kyrgyzstan, Tajikistan and Uzbekistan) are now classified as least income countries. Some 20% of the population is now living on less than US\$ 2 a day, compared with just around 3% prior to independence. Absolute poverty is as high as 68% in Tajikistan, 50% in Kyrgyzstan and 40% in Armenia.

Prior to independence, the CAC Republics were economically interdependent within the centrally managed Soviet economy. Agriculture contributed between 10 to 45% of gross domestic product and employed between 20 to 50% of the national labour forces. Each Republic was agriculturally specialized according to its agroclimatic conditions, with production distributed through the Soviet trade system. Following dissolution of the USSR and the collapse of existing trade arrangements, exporters lost their export markets and importers lost their food supply. The newly independent Republics were left with the task of developing their own independent economies.

This transition from the centrally planned economy under Soviet system to independent market-oriented economies has had severe consequences. The agricultural sector has contracted significantly; agricultural output fell by almost 50% between 1991 and 1999. Although there are signs of recovery, agricultural and food production indices still remain between 60 and 90% of the pre-independence levels. Per capita calorie supply in the region is also now less than the average for the developing world.

In short, while many other regions in the developing world are maintaining or improving their agricultural productivity and, in many cases, achieving economic growth and reductions in poverty, *the CAC region, on the contrary, has witnessed rapid declines in agricultural output and an unprecedented increase in the extent and degree of poverty in its population.* Living standards have already declined and large sections of the population, especially in rural areas, are worse off than they were under the Communist regime. The region is in danger of spiralling into declining agricultural production, increasing food insecurity and poverty.

The CAC region occupies a total land area of 410,000 km² of which around 70% (296,000 km²) is agricultural land. However, only 14% of this area is under arable and permanent crops, the remainder being under permanent pasture. Only 30% of the total cropped area is irrigated. However, this is distorted by the vast drylands of Kazakhstan, of which only 8% is irrigated; in the remaining countries the percentage irrigated area ranges from 50% to almost a 100% in Turkmenistan. The region is highly diverse in geography, climate and natural resources. Rainfall is variable and uncertain, and the region is subject to periodic droughts. Much of the area is subject to extremes of cold winters and hot dry summers, which limit cropping options.

Following independence, the large State farms inherited the problems already manifest in the high-input, energy-intensive agricultural production methods adopted under the Soviet system. Intensive irrigation and poor drainage management also resulted in water logging and salinization of soils. Also, for the lack of resources, the former State-operated, large-scale irrigation system is collapsing. With the demise of the supporting central supply and subsidy systems, there have been dramatic declines in the use of inputs such as fertilizers and farm machinery. In Kazakhstan, both the area harvested and yields have declined, with large areas of arable land left fallow. After independence, sale of livestock was often the only means for producers to earn living. Massive sales and the local consumption of stock have resulted in huge reductions in aggregate herd size.

Agrarian reforms launched in 1991 have tended to focus mainly on land reforms consisting of "decollectivization" of the large State-owned enterprises and privatization of holdings. The extent of privatization varies by country; however, in general, a three-tier system of production units is emerging, comprising: (i) various forms of collectively-run units, including former State-run enterprises, joint stock companies, shareholding and cooperative arrangements; (ii) individually owned, small to medium-sized private commercial farms; and (iii) subsistence household plots.

A large part of the agricultural output is now generated by household plots, and these have offered an important safety net for households struggling to cope with the economic transition. Today, it is estimated that 16% of the agricultural land is cultivated in household plots and private farms and nearly all livestock are now held in small herds on smallholdings. However, these still function primarily as subsistence rather than a market-oriented sector. The emerging farmers are inexperienced in operating small farm businesses and need help in developing new farm enterprises and appropriate technologies. Management of irrigation structures remains centralized, structures are inefficient and inappropriate for individual farmers, and issues of distribution and delivery to private farms is a major challenge. Effective extension and farmer advisory services, and credit facilities for the emerging smallholder sector have not yet been established.

Decollectivization has also raised issues of land tenure, access and use rights.

Due to the collapse of trade within the former Soviet Union and lack of foreign exchange reserves, the governments of CAC are giving priority to securing the domestic supply of basic food commodities. Countries have focused on food self-sufficiency, particularly self-sufficiency in cereals, and the production of cereal crops to meet domestic food demands has, therefore, taken precedence. The area sown to cereals has increased by 24% since 1992; 40% of the arable area of CAC is now sown to cereals, of which 80% is under wheat. Conversely, in Kazakhstan, which was by far the largest producer and exporter of cereals in CAC, both area and yields of cereals have declined; Kazakhstan's wheat production has fallen by some 40% over the last decade, whereas the area has also declined by 40% (around 11 million ha), having most of it as fallow, while in the rest of the region grain production has increased by some 124%, due to an increase in area.

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. However, the reform process has focused mainly on land reforms, often without the supporting institutions and mechanisms for emerging private farmers. The centralized product markets and input supply channels have disappeared and local markets are the only channels available to smallholders. Marketing has been replaced by bartering in exchange for inputs. This collapse of the marketing system has added to the disincentives in agricultural production.

Assistance is needed in building market institutions, in reforming the markets and in establishing trade links with a view to cutting down 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, especially of small holders. Deterioration of storage, processing and distribution facilities add to the problem. Given lack of markets, there is no incentive for investment (public or private) in processing. Agriculture has the potential to be a key earner of foreign exchange. Research is needed to identify policies that enhance the flow of food and agricultural commodities (both inputs and outputs) within as well as outside the region.

The collapse of the Soviet Union has not only disrupted production and trade, *it has also had considerable impact on the research systems.* In the past, agricultural research system of the Soviet Union was well-funded, science-based, and highly centralized. It provided the advantages of an elaborate research network, communication forum, and information and documentation system. But, the institutions created by the Soviet Union were designed to play a specific role in the Soviet agro-industrial complex, which no longer exists. While the newly independent Republics have inherited a wealth of national research experience

from the Soviet Era, which provides a foundation on which to build collaborative research, they are ill-equipped to respond to changes in the structure of their agricultural sectors and emerging market economies. In particular, they lack the institutional and human capacity for policy formulation and implementation.

Research systems have been staffed, for the most part, with highly trained scientists, but shortages of funds have led to a significant exodus of staff from research. Lack of contact with the international scientific community has caused a technology lag and prevented scientists from keeping abreast of current scientific achievements. The level of coordination and linkages within and between National Agricultural Research Systems (NARS) are weak, and scientists feel isolated. During the Soviet Era, extension was handled through a centrally planned research and distribution system of State enterprises. Links between research and producers has been broken with the breakdown of the central planning system. Researchers now have no formal channels through which to disseminate information, knowledge, and the new technologies. Also, the language barrier has emerged as a big constraint.

Following a ministerial-level meeting held in Lucerne, Switzerland, in 1995, and the recommendation of a CGIAR-commissioned Task Force in 1996, a decision was made to expand the geographical mandate of the CGIAR to include Central Asia and the Caucasus countries. ICARDA took the lead in initiating consultations with the CAC NARS and a consortium of nine CGIAR centers (CIMMYT, CIP, ICARDA, ICRISAT, IFPRI, ILRI, IPGRI, ISNAR, and IWMI) was established in 1997. Under the leadership of ICARDA, the Consortium developed a CGIAR Collaborative Program for Sustainable Agricultural Development in Central Asia and the Caucasus, which started operating in 1998. The Consortium now includes IRRI as well. Considerable progress has been made through collaborative research in various aspects of agricultural development in the region.

The symposium on Central Asia, held in Indianapolis, was an important step forward in understanding the nature of agriculture-related problems faced in Central Asia and to have an assessment of joint research efforts made under the Consortium. During the seminar, a large number of presentations were dedicated to water management issues, being the most critical in dry areas. These included papers highlighting research findings of ICARDA, The International Water Management Institute (IWMI) and The Center for Development Studies (ZEF)/Bonn University on water resources status, development of ground water salinity, improved on-farm water management strategies, increasing water-use efficiency and drainage water reuse.

The workshop participants discussed principles of development of sustainable agricultural systems in Central Asia. Presentations in this area covered such issues as agro-climatic mapping, harnessing soil resources for development, soil organic

carbon in agro-ecosystems, developments in tillage and cropping systems, as well as constraints and research opportunities in livestock production as priorities for improving natural resources management and increasing agricultural production.

A number of presentations addressed challenges in the areas of germplasm enhancement and conservation of plant genetic resources in the region. The papers presented invariably included the activities of ICARDA and CIMMYT covering agro-biodiversity conservation, improvement of crop productivity, promoting sustainable wheat-based and maize-based cropping systems as well as present status and future prospects of food legumes.

The symposium also highlighted the importance of international cooperation for pursuing the agenda of agricultural research for development. ICARDA through its Regional Program in Central Asia and the Caucasus (CAC) and the CGIAR Consortium on Sustainable Agriculture in CAC are facilitating the process of research partnership among NARS to address key priority areas for accelerating agricultural growth in the region. Hence, this publication is a step forward in having better understanding of both challenges and opportunities relating to agricultural development in Central Asia.

Editors

An Overview of Agriculture in Central Asia and the Caucasus and CGIAR Program for Sustainable Development

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ABSTRACT

The region of Central Asia and the Caucasus has attained considerable importance since independence of these countries from the former Soviet Union in 1991. These economies in transition are facing enormous challenges and, at the same time, offer tremendous opportunities. Concerns of poverty, food security, and natural resource management are indeed alarming. Accordingly, the Consultative Group for International Agricultural Research (CGIAR) initiated a systemwide regional program in Central Asia and the Caucasus (CAC) region involving all eight countries and nine CGIAR Centers in 1998 in a consortium mode to strengthen partnership in agricultural research for sustainable development.

The CGIAR program for CAC has addressed six thematic areas in view of their priorities. These are: (i) germplasm enhancement; (ii) crop diversification; (iii) soil and water management; (iv) feed and livestock management; (v) genetic resource management; and (vi) strengthening of the national agricultural research systems. The program has made significant progress and several new crop varieties and production technologies have been developed in order to ensure increased production and profitability for the resource-poor farmers of the region. This paper describes some of these achievements and demonstrates the strength of intra-regional research collaboration in attaining sustainable agricultural production, being so critical for the overall growth and development in the region.

THE REGION: AN OVERVIEW

The region of Central Asia and the Caucasus (CAC), encompassing Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan in Central

Asia, and Armenia, Azerbaijan and Georgia in the Caucasus (Fig.1), has undergone tremendous economic and social shocks following the dissolution of the former Soviet Union. Economies have shrunk, incomes have fallen, poverty has increased, and food security is compromised. Gross National Income (GNI) per capita declined by an average of 40% between 1991 and 1999, compared with an average increase in other low - and middle-income countries over the same period. Six of the CAC countries (Armenia, Azerbaijan, Georgia, Kyrgyzstan, Tajikistan, and Uzbekistan) are now classified as least-income countries, and GNI per capita for CAC region as a whole is now even less than the overall average for developing countries as a whole.



Fig. 1. The region of Central Asia and the Caucasus.

Prior to independence, the CAC countries were economically interdependent within the centrally managed Soviet economy. Agriculture contributed between 10 to 45% of Gross Domestic Product (GDP) and employed between 20 to 50% of the national labour forces. Each Republic was agriculturally specialized according to its agroclimatic conditions, with production distributed through the entire Soviet trade system. Following dissolution of the USSR and the collapse of existing trade arrangements, exporters lost their export markets and importers lost their food supply. The newly independent Republics were left with the task of developing their own independent economies.

As is evident, there had been uneven progress in the process of transforming the formerly centrally planned economies into market economies, and the process has led to significant consequences in some countries; on one side, the importance of agriculture in the region increased through its share and, on the other, the agricultural production dropped in the mid-1990s. While it recovered in some countries, on aggregate, agricultural crop and livestock production indices are still ranging between 50-90% of the pre-independence base of 1989-91.

Agriculture is of paramount importance in the region. Its percentage contribution to GDP has increased in many countries since the countries gained their independence (Table 1), but this is due to a decline in other sectors rather than due to an increase in agricultural production. About 70% of the total area i.e., 418 million (M) ha is classified as agricultural land. Of this, only 15% is arable land, of which 24% is irrigated. Wheat, cotton, and livestock are most important agricultural commodities (Table 2). About 85% of the agricultural land is under permanent range, being used for extensive livestock production. The agriculture in the region is diverse and has a great potential to revitalize faltered economies of the CAC countries by means of improved productivity and production through agricultural research for development.

Table 1. Indicators of country profile.

Country	Total area	Arable land	Population		GNI per capita	GDP	Agriculture	
			Total	Rural				
	M km ²	M ha	M	%	M	\$US	billion \$US	% GDP
Armenia	2.9	1.4	3.8	30	1.1	520	1.9	40.0
Azerbaijan	8.6	4.2	8.0	42.7	3.4	600	5.3	14.5
Georgia	6.9	3.0	5.0	39.3	3.0	630	3.0	32.1
Kazakhstan	271.3	24.0	14.9	43.6	6.5	1,260	18.2	7.4
Kyrgyzstan	19.8	1.4	4.9	66.7	3.2	270	1.3	39.4
Tajikistan	14.3	0.8	6.2	72.5	4.5	180	0.9	22.7
Turkmenistan	48.0	1.4	5.2	55.2	2.9	750	4.4	27.3
Uzbekistan	44.7	5.0	24.8	63.1	15.8	360	7.7	34.9

Source: World Bank Development Indicators Database (2000) and Asian Development Bank Key Indicators Database.

Table 2. Cropped area, production and productivity of main crops in CAC region, 2001.

Country	Wheat			Barley			Cotton ¹	Rice		
	Area	Production	Yield	Area	Production	Yield		Area	Production	Yield
	10 ³ ha	10 ³ t	t ha ⁻¹	10 ³ ha	10 ³ t	t ha ⁻¹	10 ³ ha	10 ³ ha	10 ³ t	t ha ⁻¹
Armenia	110	298	2.7	84	59	0.7	-	-	-	-
Azerbaijan	587	1,55	2.6	128	295	2.2	80	5.3	30	5.6
Georgia	87	306	3.5	17	15	0.8	-	-	-	-
Kazakhstan	10,82	12,91	1.2	1,744	2,330	1.3	118	71	300	4.2
Kyrgyzstan	478	1,31	2.7	122	280	2.2	33.7	2.4	8	3.2
Tajikistan	292	233	0.7	30	18	0.6	-	14.7	25	1.7
Turkmenistan	750	1,20	1.6	50	45	0.9	621	13	34	2.6
Uzbekistan	995	3,13	3.1	67	58	0.8	1,505	92.5	178	1.9

Source: ICARDA Regional Office for CAC (2001). ¹ Production and yield data not available.

EMERGING CHALLENGES

The CAC region occupies a total land area of 416,000 km², of which around 70% (296,000 km²) is agricultural land. However, only 14% of this area is under arable and permanent crops, the remainder being under permanent pasture. Only 30% of the total cropped area is irrigated. However, this is distorted by the vast drylands of Kazakhstan, of which only 8% is irrigated; in the remaining countries, the percentage of irrigated area ranges from 50% to almost 100% in Turkmenistan. The region is highly diverse in geography, climate, and natural resources. Rainfall is variable and uncertain, and the region is subject to periodic droughts. Much of the area is subject to extremes of cold winters and hot dry summers, which limit cropping options.

Following independence, the large State farms inherited the problems already manifested in the high-input, energy-intensive agricultural production methods adopted under the Soviet system. Intensive irrigation and poor drainage management also resulted in waterlogging and salinization of soils. Also, for the lack of resources, the former State-operated, large-scale irrigation system is collapsing. With the collapse of the supporting central supply and subsidy systems, there have been dramatic declines in the use of inputs such as fertilizers and farm machinery.

Structural Reforms

A large part of the agricultural output is now generated by household plots, and these have offered an important safety net for households struggling to cope with the economic transition. Today, it is estimated that 16% of the agricultural land is cultivated in household plots and private farms and nearly all livestock is now held in small herds on smallholdings. However, these still function primarily as a subsistence rather than a market-oriented sector. The emerging farmers are inexperienced in operating small farm businesses and need help in developing new farm enterprises and appropriate technologies. Management of irrigation structures remains centralized, structures are inefficient and inappropriate for individual farmers, and issues of distribution and delivery to private farms is a major challenge.

Food Self-Sufficiency vs. Food Security

Due to the collapse of trade within the former Soviet Union and lack of foreign exchange reserves, countries have focused on food self-sufficiency, particularly self-sufficiency in cereals, and the production of cereal crops to meet domestic food demands has, therefore, taken precedence. The area sown to cereals has increased by 24% since 1992; 40% of the arable area of CAC is now sown to

cereals, of which 80% is under wheat. Conversely, in Kazakhstan, which was by far the largest producer and exporter of cereals in CAC, both area and yields of cereals have declined; Kazakhstan's wheat production has fallen by about 40% over the last decade, and the area has also declined by 40% (around 11 M ha), having most of it as fallow, while in the rest of the region grain production has increased by about 124% due to an increase in area.

Markets and Trade

The centralized product markets and input supply channels have disappeared and local markets are the only channels available to smallholders. Marketing has been replaced by bartering in exchange for inputs. This collapse of the marketing system has added to the disincentives in agricultural production. Assistance is needed in building market institutions, in reforming the markets and establishing trade links with a view to cut down transaction costs, mitigate risks, build social capital and redress missing markets. Also, research is needed to identify policies that enhance the flow of food and agricultural commodities (both inputs and outputs) within as well as outside the region.

Plant and Animal Genetic Resources

The CAC region is the center of origin of a number of economically important crop species and possesses a wealth of plant and animal genetic diversity. There exists one of the world's best collections of fruits and nuts, as well as wild relatives and progenitors of regionally and globally important food crops, including cereals and grain legumes. With changes in farming systems, intensification of cereal cropping, abandonment of orchards and tree crop production, and increased pressure on pasture areas, the region is at the risk of losing its landraces and wild relatives of agricultural crops. The germplasm base in the global collections from these Republics is also very limited, and there is growing concern about the viability status of germplasm presently being held in local collections. The region also represents a large diversity of livestock breeds. Based on data from on-going activities, it is apparent that this diversity is under threat as a result of the large reduction in livestock populations and the collapse of breeding schemes after the dissolution of the Soviet Union.

The National Agricultural Research Systems

The collapse of the Soviet Union had considerable impact on the research systems. While the newly independent republics have inherited a wealth of national research institutions from the Soviet Era, which provides a foundation on which to build collaborative research, they are ill-equipped to respond to changes in the

structure of their agricultural sectors and emerging market economies. In particular, they lack the institutional and human capacity for policy formulation and implementation. Moreover, links between research and producers has been severed with the breakdown of the central planning system. Researchers now have no formal channels through which to disseminate information, knowledge, and the new technologies. Also, the language barrier has emerged as a big constraint, since most nations are following the policy of greater official use of local languages, replacing Russian.

Opportunities

The CAC region offers tremendous opportunities for agricultural development, since the two important pillars of agriculture, i.e., institutional infrastructure and human resources do exist. In addition, traditional agricultural practices, rich genetic wealth (both plants and animals), and vast arable areas and rangelands provide enormous potential for future development. Also, the use of quality seed of high-yielding varieties, fertilizers, and pesticides is minimal. The area under food crops as well as productivity levels have declined in some countries and, similarly, the livestock population has been reduced due to lack of viable markets, remunerative prices, and degradation of rangelands. The region presently faces a lack of food and fodder resources. Water use-efficiency has also decreased due to poor maintenance of the vast irrigation systems and wasteful use of water.

Hence, tremendous opportunities exist if new improved technologies are made available to farmers. Also, good scope exists for the conservation of vast plant and animal genetic resources. Similarly, there is good potential for the *diversification of agriculture* in the region. This could all be possible through strong partnership in agricultural research for development to address concerns of *food security, poverty alleviation, conservation of natural resources*, and providing scientists of the region with the knowledge needed to address the problems. Briefly, there are three components required to utilize the ample opportunities for the benefit of the region:

1. Development, dissemination and application of appropriate technologies that are cost-efficient and income-generating.
2. Development of a conducive policy environment, together with development of supporting rural institutions.
3. Strengthening the capacity of the National Agricultural Research Systems (NARS) in the following areas:
 - Maintaining client-oriented research, through institutional strengthening, development of appropriate research methods, and skills development of the next generation of researchers.

- Channels through which to disseminate information, knowledge, and new technologies.
- Conveying information to policymakers to induce enabling policy reforms.
- Regional integration and knowledge-sharing.

PROGRAM FOR CENTRAL ASIA AND THE CAUCASUS

In 1995, a CGIAR Task Force on Central/Eastern Europe and the States of the former Soviet Union was formed to identify the needs of agricultural research of these countries. In December 1995, ICARDA in collaboration with BMZ/GTZ, Germany, organized a workshop that brought the key scientists and research managers of the CAC countries together for the first time after the breakup of the Soviet Union. During the workshop, which also laid the foundation of a CAC regional forum in agricultural research, the first regional priority-setting exercise was done. A consultation meeting between the CGIAR Centers and Central Asia and the Caucasian NARS was organized by ICARDA in Tashkent in September 1996. The Consultation reinforced the need for collaboration in agricultural research. The Task Force recommended to the CGIAR to extend support for agricultural research and human resource development by expanding its geographic mandate to the CAC region.

The CGIAR accordingly approved this recommendation at the International Centers Week (1996), and encouraged the CG Centers to develop partnerships with the NARS in CAC in their respective mandated areas of agricultural research. Accordingly, in October 1997, the nine CG Centers (CIMMYT, CIP, ICARDA, ICRISAT, IFPRI, ILRI, IPGRI, ISNAR, and IWMI) agreed to form a Consortium, with ICARDA being the lead Center. Recently, IRRI has also joined as the tenth Center of this Consortium. The main objective of the Consortium is to develop a strategy for inter-center partnership for collaborative research with greater involvement of the national programs in the region. The Consortium eventually developed a CGIAR Collaborative Research Program for CAC in May 1998, and launched it in September 1998, with approval of the Steering Committee in a meeting held in Tashkent, Uzbekistan. Also, a Program Facilitation Unit (PFU) was established in the CAC-RP Office of ICARDA in Tashkent. The Unit has since then been providing a facilitation function for the inter-center and inter-NARS initiatives in the region.

REGIONAL PRIORITIES

Since the establishment of the Collaborative Program, there have been extensive consultations between CG Centers and the NARS to identify and prioritize thematic research areas (for instance, germplasm improvement, soil and water

management, livestock development, policy orientation, and NARS institutional strengthening). With the seed money provided by the CGIAR and additional funds raised by the participating centers, the Program has made significant progress. Annual meetings between all participating CG Centers and NARS, have been held regularly at which work plans are reviewed and adjusted according to re-assessed priorities.

During the year under report, in line with the "bottom-up", priority-setting approach adopted by the CGIAR under "Plank 4" of the CGIAR's vision and strategy, the CAC Regional Forum and ICARDA organized a "brainstorming" meeting with NARS leaders and representatives of concerned CG Centers and donors in September 2001, in Tashkent in May 2002. According to the broad consensus, the following research priorities were identified:

- Productivity enhancement of crops and a focus on seed development, with major emphasis on cereals, legumes, oilseeds, fruits, and vegetable crops. Breeding of high-yielding varieties with resistance to diseases, pests, drought and salinity. Searching for genotypes that can withstand better the low input conditions.
- Soil and water management for sustainable agriculture, including emphasis on nutrient-and water-use efficiency, on-farm water management, marginal water utilization, salinity, drainage, and conservation tillage.
- Conservation of genetic resources (crops and livestock) in view of the existing rich diversity in the Region.
- Livestock improvement and management with emphasis on market-oriented breed improvement, health, feed management, and rangeland resources.
- Crop diversification, with greater emphasis on incorporation of legumes in cropping systems for long-term sustainability, for better income generation, and for household nutrition security.
- Post-harvest management, storage and value-addition of crops, livestock, fruit and vegetable products that can help small and marginal farmers in rural areas.
- Socio-economic and policy research for infrastructure development, economic feasibility of technologies, resource evaluation, marketing, finance, and policy interventions for required adjustments in market economy.
- Strengthening of NARS and human resource development, with greater emphasis on training, including language training.

Later on, these priorities were re-assessed more globally when researchers and research administrators from throughout Central and West Asia and North Africa (CWANA) met at ICARDA headquarters in May 2002, to integrate the regional agricultural research priorities into the CGIAR agenda. Therefore, based on the

revised analysis of constraints and opportunities for agricultural research and development in the CAC region, the research priorities for CAC region have been identified as follows:

Table 3. Research priorities for Central Asia and the Caucasus.

Priority	Management		Socio-economics	Cross-cutting Issues
	Germplasm	Natural Resource		
1	Improvement Biotechnology Genetic resource Conservation	Water Soils Rangeland	Marketing, commerce and trade Post-harvest technologies	Human resource development, Capacity-building Information, communication, technology
2	Seed production, Diversification	Biodiversity	Quality, added-value, Institutional policies	Intellectual property rights, Crisis-risk management
3	Integrated pest management	Integrated crop management	Impact assessment	Biosafety and quarantine, Indigenous knowledge

ACHIEVEMENTS

The CGIAR Consortium for CAC has already made considerable progress during the last three years of its existence and major achievements are projected here theme wise:

Germplasm Enhancement

Major constraints to improving crop production are the lack of improved high-yielding varieties and poor access to germplasm. Over the last 10 years, practically no new varieties could be released for want of improved germplasm. Research activities on germplasm enhancement have focused on testing different crop varieties to identify promising breeding material with resistance to both biotic and abiotic stresses. In this context, ICARDA, CIMMYT, ICRISAT and CIP have provided very timely support to all the CAC countries, leading to very encouraging results, such as:

Varietal Improvement

- Annually, about 4200-4500 entries from 80 different nurseries of cereals, legumes, groundnut, and potato supplied by ICARDA, CIMMYT, ICRISAT and CIP are tested in CAC region. Practically in all the eight CAC countries, the new promising breeding material has been identified, which is being used now either for improvement of the local germplasm or for direct multiplication and introduction on farmers' fields.

- Released promising varieties so far under this program had been the following: *Winter wheat*-Ani-326, Azametli-95, Gobustan, Guncha, Bitarap, Garagum, Dostlik, Mtskhetsi-1, Jamin, Norman, Tacika; *Winter barley*-Adel, Bakharly (Rihane-03); *Spring barley*-Mamluk; *Chickpea*-Narmin, Elixir, ICARDA; *Lentil*-Pablo.
- In countries of Central Asia and the Caucasus, the important role of legumes is being increasingly felt since testing of chickpea, lentil, vetch, and groundnut, started under the Program. Collaboration during last 3-4 years has resulted in identification of some promising breeding material, which has been taken for seed multiplication and for on-farm trials and demonstrations.

In summary, during the last 4 years of collaborative research, six promising crop varieties have been developed, e.g., winter wheat (2), winter barley (1), spring barley (1), chickpea (1), and lentil (1) have already been released in the region based on their superior performance. These varieties have consistently recorded 30-40 % higher yield with superior cold-tolerance and disease-resistance over the local checks. In addition, more than 25 varieties of different crops based on their superior performance are presently being tested in the State Varietal Trials, and are awaiting decisions for their release and wide-scale adoption.

Seed Production

Quality seeds of high-yielding varieties are critical for further dissemination; thus, emphasis was laid on seed development activities in the Region. On-farm trials and large-scale demonstration plots were also established. The seed production activities included the following:

- Wide-scale promotion of on-farm trails and field demonstrations for evaluation and seed multiplication of new varieties on farmers' fields was introduced jointly with NARS and CIMMYT in Tajikistan (four locations), Azerbaijan (three locations) and Uzbekistan (22 locations). These initiatives attracted the attention of administrative authorities and also received very positive response from farmers.
- ICARDA supported the Karakalpakstan Republic of Uzbekistan in seed multiplication of the salt-tolerant barley variety Unumli-Arpa (6 t), and the new promising winter wheat variety Gairat (2 t). Seeds of Dostlik variety (5 t) were procured from Turkey (4 t) and Tajikistan (1 t) for further seed multiplication (around 100 t) in Tashkent and Syr-Darya regions of Uzbekistan. This variety is likely to be released soon in Uzbekistan in view of its seed availability and good performance under salt-affected land as well.
- About 300 kg of very early winter wheat varieties (Chillaki and others) were procured for Khojent region of Tajikistan. As many as 1000 t of the spring

barley variety Mamluk has already been produced by Armenia, and 1500 kg of the chickpea variety Elixir and 600 kg of the lentil variety Pablo has been produced in Georgia. In other countries, breeder seeds of promising varieties were distributed to farmers, experimental stations, and private farms to speed up the process of multiplication.

- Twenty tons of the newly released winter wheat variety Mtskhetis-1 have been produced in Georgia, and 20 t of the winter wheat variety Egemen were produced in Kazakhstan before its submission for official testing and release.

Integrated Pest Management

Activities on integrated pest and disease management are an important part of germplasm improvement. Several surveys have been carried out by the scientists of ICARDA and CIMMYT in collaboration with specialists from USA, Canada, and Australia to study the overall situation in the CAC countries and develop appropriate mechanisms and recommendations for controlling the most severe cereal disease, yellow rust, and the most pestiferous insect, Sunn Pest. The main achievements had been:

- Extensive surveys of cereal diseases have been conducted and identification of physiological races in Azerbaijan, Kyrgyzstan, Tajikistan, and Uzbekistan accomplished. Data for mapping the distribution frequency of new races have been collected. Identification of effective and defeated resistance genes to yellow rust could be possible. Recommendations for replacement of varieties susceptible to yellow rust with those of the resistant ones, and application of fungicides for the protection of susceptible varieties, have been made.
- Research activities on studying the effect of the biological agent TG-1 on cereals to control root rot diseases were initiated by ICARDA scientists in collaboration with the Institute of Genetics and Experimental Biology, Uzbekistan. The pathogenic fungus TG-1 has already shown a significant effect against all kinds of root rot diseases of cotton with evident growth stimulation.
- Monitoring of the leaf rust population based on the isogenic lines on spring wheat has been conducted as part of CIMMYT global survey mission. Effective genes and sources of resistance have thus been identified.
- ICARDA, in partnership with University of Vermont, USA, has developed a biological control method against Sunn Pest using an insect-killing fungus collected from the affected insects. New strains of fungi have also been identified with almost 90-100% effectiveness.

Crop Diversification

With the current land reforms and the emergence of small-farm units, the role of alternative crops to replace monoculture practices becomes very important.

Introduction of alternative crops will ensure the much-needed diversification of agriculture. In this process, several alternative crops have been identified that are likely to be more profitable than wheat and, therefore, have potential for wide-scale adoption in near future, e.g., chickpea, lentil, buckwheat, and field peas.

Similarly, diversification would demand changing existing food habits. Food legumes have already been found to be a good meat replacement for poor people in Georgia, Uzbekistan, and Tajikistan. On the other hand, food legumes could also be exported to other countries, especially in South Asia. Crop diversification may also help in reducing barren fallow areas, such as in Kazakhstan. Sugar beet and maize, followed by food legumes, were also identified as economical crop rotations for irrigated conditions in Kyrgyzstan.

In wheat and cotton-based cropping systems, there are opportunities to introduce food legumes as double crops and forages for growing in the winter period. In Tajikistan, promising crops for double-cropping after harvest of winter wheat are cotton, rice, buckwheat, and millets. There are many useful crops that now need proper attention for both research and production, such as, potato, soybean, cowpea, rice, maize, safflower, sunflower, groundnut, rapeseed and alfalfa. In this context, new germplasm different countries and international centers is being tested.

Soil and Water Management

For the new nations of Central Asia and the Caucasus to attain long-term, sustainable growth, and to increase agricultural productivity, it is critical that their enormous natural resources are managed more efficiently. Integrated soil and water resource management must form the basis for policy decisions at all levels. Two CGIAR centers, ICARDA and IWMI (International Water Management Institute), are addressing the issues of natural resource management at on-farm and basin levels, respectively, through the following main projects: "On-farm Soil and Water Management for Sustainable Agricultural Systems in Central Asia", and "Integrated Water Management in the Fergana Valley."

The objectives of the Soil and Water Project funded by the Asian Development Bank (ADB) and implemented by ICARDA were to: (i) increase agricultural productivity and production through improved management of cropping systems, including optimal use of water resources and improved management of soils and nutrients; and (ii) achieve sustainable irrigated cropping systems through an appropriate farm-level management of irrigation and drainage and safe use of marginal water sources. The major findings of the Project are:

Water-Conserving Irrigation Technologies

- In steeply sloping areas, soil erosion and significant water losses for surface runoff are major constraints to sustainable agriculture. At the Boykozon

integrated research site, Uzbekistan, improvement in traditional 'joyak' (zigzag) irrigation technology demonstrated reduced soil erosion (from 2.7 to 0.12-1.10 tha^{-1}) and proved to be efficient for cereal, vegetable, and melon crop production.

- Uniformity of water distribution on irrigated sloping areas is usually low. Application of improved irrigation technologies using portable chutes has provided a uniform water jet to each furrow and has also increased water productivity by almost 50-100%. This technology is suitable for adoption on small-scale farms.
- Growing annual and perennial crops and vines on terraced lands in Tajikistan was found to be an efficient farming practice for water harvesting and moisture conservation. At the Fakhrabad site, different mulching technologies have been tested to ensure better moisture conservation. The effect of plant residue mulching was similar to that of black and transparent plastic film application that are associated with higher input costs.
- At the demonstration site in Kyrgyzstan, application of water-saving technologies through utilization of water siphons and cleaning of the drainage network contributed to a considerable decrease in groundwater level; taking into consideration weather conditions of the year 2002, when the precipitation has significantly exceeded the average annual rates, this appeared to be a very timely action.

Minimal Tillage for Water and Resource Conservation

- In rainfed semi-arid conditions of northern Kazakhstan, minimum and zero tillage proved to be promising compared to the general practice of deep conservation tillage.
- In rainfed conditions of southern and southeastern Kazakhstan, shallow and deep conservation tillage gave almost the same grain yield as that of ploughing, but reduced conservation tillage was found to be the most economical. Though conservation tillage is now widely adopted only in Kazakhstan, it could be possibly spread to neighboring countries that grow grain.
- In Turkmenistan, for two consecutive years, soil tillage at various depths (from 10-12 cm to 30-32 cm) before planting winter wheat did not significantly affect grain yields; whereas reduced conservation tillage contributed to resource saving and allowed timely planting. Water productivity under reduced tillage at 10-12 cm was 25% higher than that of deep ploughing at 30-32 cm.
- In Tashkent province of Uzbekistan, on a typical non-saline gray soil, rotor cultivation (10-12 cm deep) with sub-soiling at 45 cm provided the highest yield of winter wheat compared to traditional deep moldboard ploughing.

- In the Hissar Valley, Tajikistan, on an irrigated dark gray soil, deep ploughing at 40-42 cm ensured higher soil moisture content and, as a result, higher yield of winter wheat compared with traditional ploughing at 28-30 cm.

Marginal Water for Irrigation: Fodder, Industrial and Tree Crops Plantations

- Utilization of treated wastewater for irrigation of fodder crops and tree plantations was tested in Sorbulak Lake area in Kazakhstan. After mechanical and biological treatment, the treated wastewater of Almaty city flows to Sorbulak collector with a capacity of about 1.0 M m³. Based on the 1999-2001 research results, treated wastewater proved to be an important source of nutrient supply, ensuring sustainable yields of fodder crops and good growth of tree plantations. The content of heavy metals (Zn, Fe, Cd, Cu, Cr, Ni, Pb) in fodder crops produced under wastewater irrigation did not exceed the threshold limits for these elements. A slight increase in Co content was recorded once in Jerusalem artichoke, sunflower, and sugarbeet.
- Treated wastewater of Hodjent city was also tested for cotton irrigation at Kyzyltukay experimental site in northern Tajikistan. Besides minimizing the risk of fresh water contamination, the use of treated wastewater for irrigation reduced dependence on chemical fertilizer use, thus significantly reducing production costs.
- At Dustlik experimental site in Fergana Valley, Uzbekistan, drainage water was tested for irrigation of recently planted forest shelterbelts consisting of Californian poplar, mulberry, pomegranate, almond, fig, and pistachio trees. The rooting rate of most saplings varied from 69 to 100%, except that of fig trees, which was only 18%. Winter wheat was planted in the field protected by these shelterbelts.
- Drainage water utilization for irrigation of winter wheat was tested at the experimental site located at the Vatan Farm, central Turkmenistan. Water from an open drainage system, with salt content varying between 2.0-3.0 g/L was used for irrigation in two experimental variants of which one involved its alternation with fresh water from the Karakum canal. The yield of winter wheat in the two experimental treatments was lower compared to irrigation by surface water by 14 and 19% for alternated and drainage water irrigation, respectively.

The objectives of the first phase of the Project, such as establishing experimental sites and identifying and testing technologies to improve soil and water management, were successfully achieved, but the majority of findings need further verification and refinement, as well as dissemination. Some issues of socio-economic, policy and technology transfer need to be addressed in detail.

There are some identified, adapted and improved technologies that have been tested at small experimental sites and are now ready for on-farm testing over large areas. Therefore, the Project Implementation team is working on development of a proposal for the Second Phase.

The ICARDA-IWMI collaborative activities in Karakalpakstan were initiated in 2002 to conduct research and prepare a wider project proposal for the potential donors on reforming agriculture and the water sector in Uzbekistan. A joint team has already formed to tackle institutional reforms in agriculture and water management in the drought-affected Karakalpakstan region. The Project includes a component on establishing of Water User Associations that will be addressed by IWMI, whereas ICARDA's research activities will target increased economic efficiency of crop production through user associations.

The objectives of the second Project on "Integrated Water Management in the Fergana Valley" founded by the Swiss Development Cooperation (SDC), in conjunction with IWMI, were to: (i) introduce and pilot-test integrated water resources management and water users' participation among the water management institutions in the pilot canals in the Fergana Valley; and (ii) demonstrate options for increasing water and land productivity at all levels of water management hierarchy of the other. The Project was initiated in May, 2002.

Feed and Livestock Management

The three priority livestock research themes were identified by NARS through a consultation process sponsored by ICARDA and ILRI: (i) increasing feed resources and efficiency of utilization; (ii) conservation and utilization of ruminant genetic resources under new production conditions; and (iii) policy options to create enabling environments for improved small-holder production and markets. Accordingly, the "Integrated Feed and Livestock Production in Steppes of Central Asia" project funded by IFAD and implemented by ICARDA, was initiated in 1999, and addressed four major components: socio-economic activities; range management; feed production; livestock production, and flock management. The major findings include the following:

Socio-economic Activities

Three main farm types are presently operating in the region, e.g., *big-scale farms* (various types of cooperatives) that used to produce the main share of livestock product currently contribute up to 20%; *medium-scale farms* (private farms) recently emerged as a result of reforms and they contribute around 2-4%; and *rural households* contribute up to 95% to different countries' livestock product.

The diagnosis covering concerns of livestock producers revealed that the main problem for all types of producers is lack of forage in wintertime; in countries

where big-scale farms were dismantled, producers are experiencing a lack of resources associated with poor infrastructure; with the Soviet Union collapse, traditional markets for pelts and fine wool have disappeared, thus causing a decrease in income to the farmers.

Relating to marketing, the studies have revealed that local markets now provide more income to producers than selling products to processing companies as before (except Kazakhstan); among all types of products, the sale of live animals generates the maximum income; and sheep milk may also become an additional source of income.

Range Management

Rehabilitation technologies are being introduced to recover overgrazed rangelands. *Haloxylon* and *Salsola* planted in range strips got established quite successfully on 8 ha at the Yzgant site, Turkmenistan, in spite of a 3-year drought and *Haloxylon-Kochia-Salsola* strips on 9 ha at Buhtulin, Kazakhstan, and on 58 ha at Nurota, Uzbekistan. The survival rate of *Haloxylon* bushes ranged from 23-81%, *Kochia* from 78-86%, and *Salsola* from 90-100%. Collection of range species' seeds and establishment of nurseries for future range rehabilitation was done in Kazakhstan, Uzbekistan, and Turkmenistan. Seeds will be used for planting in larger areas next year.

Testing options for the rational utilization of rangelands involve a mobile flock to restore seasonal rotational grazing with participation of farmers and assistance of farmers' federation has been organized in the community Birlik, Kazakhstan, which allowed pooling of small flocks of poor farmers to form a large mobile flock and moving it to remote unused range to avoid overgrazing of range around the village. In addition, the village rangeland was divided into two equal parts for the alternation of grazing on these two parts. As a result, every year one of the portions is "resting" in spring or in autumn.

Feed Production

Sowing feed mixtures as intermediate winter crops was initiated to improve the fodder availability. To help farmers improving the fodder availability in Kyrgyzstan, 20 ha of sainfoin were sown in 2000, along with barley as a cover crop. The mixed crop yielded 2 t ha⁻¹ of barley grain and 1.5 t ha⁻¹ of barley straw and sainfoin hay. In addition, the crop left about 0.7 t ha⁻¹ of stubble that was fully utilized by sheep in October. Intensive use of irrigated land for fodder production in Uzbekistan was achieved through introduction of intermediate winter crops (mixture of triticale, oat and fodder pea) for forage harvested in April followed by planting maize for grain. Net production of biomass in the experi-

mental field was 67 t ha⁻¹ of dry matter ha⁻¹ and 4.5 t of maize grain, whereas the control-widespread practice of spring planted maize for silage-yielded only 35 t of dry matter ha⁻¹.

Drainage water was used for fodder production on marginal saline lands. Four halophytes, *Klimokoptera lanata*, annual and perennial *Atriplex* and *Suaeda altissima*, were sown in Turkmenistan to test irrigation with drainage water. The results revealed that halophytes could provide additional animal fodder and improve the land use in the areas with high soil salinity.

Mulberry leaves were tested as alternative source of fodder (Uzbekistan). A trial was conducted on substitution of concentrates through introduction of mulberry leaves into feed mixtures and feed-blocks. Four groups for 7-month-old ram-lambs were formed for 60-day fattening with different diets. The highest weight gain was observed in the group where mulberry leaves were incorporated into feed-blocks as a substitute of concentrates. Feed blocks were introduced to improve the diet for sheep during wintertime and in the last period of pregnancy. The experiment was carried out from 10 January to 30 March. The diet of the experimental group was based on feed blocks produced from alfalfa, hay, barley, cotton cake, and concentrates. The control group used range grazing and additional feeding with barley when the animals stayed in barns. The weight gain of sheep in the experimental group was 10 kg/sheep compared to 0.7 kg in the control.

Flock Management

In Uzbekistan and Turkmenistan, early mating and lambing of Karakul sheep is being tested successfully to produce lambs for sale in high market price time. Lamb fattening technologies are considered here to satisfy the demand for lamb meat in late summer and having ewes ready for mating at this time. The Project started on-farm activity on sheep milking to improve farmer's diet and eventually to generate extra income. Under the project on "Conservation and Utilization of Ruminant Genetic Resources", sampling of indigenous sheep and cattle breeds in Armenia, Azerbaijan, Georgia, and Uzbekistan for molecular genetic characterization was carried out in collaboration with ILRI. A total of 416 samples were collected in the first round from 18 locations and these are being processed and analyzed at ILRI, Nairobi.

Genetic Resource Conservation

The CAC region is the center of origin of a number of economically important crop species and has rich genetic diversity. Due to financial constraints, the plant genetic resources programs are weak. Hence, the International Plant Genetic

Resources Institute (IPGRI), ICARDA and CIMMYT are working with national systems to provide support to the national genetic resource institutes to collect, conserve, and document local and exotic genetic resources. Some of the important achievements had been:

- A Central Asian and Trans-Caucasian Network on Plant Genetic Resources has been established with the support of IPGRI and ICARDA, consisting of eight plant genetic resources documentation units established in each country of the region. All eight units are making an inventory and documentation of genetic resources maintained in their national collections, for which appropriate equipment and training on documentation have been provided.
- Collection missions to all CAC countries were organized through 1998-2002. A total of 1442 accessions of cereals, food legumes and their wild relatives and forage and range species were collected. The collected germplasm is now kept by the host country and stored "in-trust" in ICARDA's gene bank, providing safety duplication.
- Regional *ex-situ* collections of pistachio and melon has been established with the purpose of enhancing conservation and using of genetic resources. It is also planned to support best world collections of apple, grapes, pomegranate, walnut, almond, and perennial cotton and vegetables.
- Based on requests from Uzbek Research Institute of Plant Industry (UzRIPI), United States Department of Agriculture (USDA), ICARDA and IPGRI have jointly agreed to upgrade the storage facility in the Gene Bank and turn it into a medium-term storage facility. Under PL-480 Fund, a sum of 57,380,000 Uzbek soum has been agreed by USDA for renovation of the present facility. USDA has also requested ICARDA to provide technical backstopping.

Strengthening of National Agricultural Research Systems

All centers have made considerable efforts in the area of *human resource development*, including training on courses, study tours, participation in international, regional and national scientific meetings and workshops, supply of computers and other research equipment. From September 1998 to June 2002, the CAC Program arranged 44 short-and long-term training courses with participation of 416 scientists, 34 study visits with participation of 67 scientists, 37 regional and national workshops with participation of 804 scientists and farmers, 14 international conferences with participation of 233 scientists, and 43 consultation planning meetings with participation of 759 scientists. A total of about 2400 scientists and farmers from the CAC countries have so far benefited from different training and human resource development activities. ICARDA alone supported and/or organized training of more than 1800 participants from the region.

Information exchange has been improved through participation in the international and regional workshops, establishing e-mail links and providing Internet access to the collaborating institutions and through CAC Newsletter and various publications, reports, etc. In the last 2 years, NARS have been provided with around 60 personal computers, 10 cars, three automatic weather stations, portable laboratory equipment and four digital cameras by ICARDA. The other Centers involved also organized the courses on data management and provided need-based equipment to their NARS partners.

FUTURE OUTLOOK

The promising results obtained from the first few years of the current collaborative research program have encouraged the members of the CGIAR Consortium and their national partners to further strengthen the existing collaboration. During the last Steering Committee Meeting of the CGIAR Program for CAC, held in Tashkent, on 24-27 June, 2002, the Centers of the Consortium once again reaffirmed their commitment to the partnership philosophy, of which the main features are to: (i) assist the CAC-NARS in their efforts to overcome the difficulties of the transition period faced by the agricultural sector; (ii) work together for a common goal of food security, enhanced productivity, environmental sustainability, economic growth and poverty alleviation in the CAC countries; (iii) share the knowledge and results achieved with other countries; and (iv) serve a facilitation role in enhancing the communication of CAC-NARS with the international scientific community and maintaining close linkages between the NARS themselves through regional and global fora.

In this process, partnership for Agricultural Research and Development (ARD) in the region has grown and has involved other CG Centers, advanced research institutions (ARIs), NARS of other regions, NGOs, etc. This could be possible due to increased donor support as well as enhanced core budget activities by some of the more active CG Centers in the region, such as ICARDA, CIMMYT, IPGRI and IWMI. Through the proposed Challenge Program on "Partnership for the Development of Sustainable Agricultural Production Systems in Central Asia and the Caucasus" and through continued support to the Systemwide Initiative by the CGIAR to enhance strengthening of the Consortium for CAC, and through new initiatives by the individual Centers, new programs and partnerships are being envisaged to provide much needed critical and rather catalytic support to all NARS in the CAC region. *The seeds of hope have been sown.* Further strengthening of partnership among all stakeholders would ensure sustainability of this program in the CAC region.

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Agroclimatic Mapping as a Tool for Crop Diversification in Central Asia and the Caucasus

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ABSTRACT

The transformation of the agricultural systems in Central Asia and the Caucasus, with a general trend towards smaller land management units, demands a better knowledge of the agricultural environments at a higher spatial resolution than was previously generated during the Soviet era. This paper presents a new set of geospatial tools, databases and methodologies that can be applied to assist the drive towards crop diversification in the region. The new approach is based on the spatialization of individual climatic parameters using an appropriate interpolation method in which terrain, in the form of a regional digital elevation model (DEM) at 1-km resolution, constitutes an auxiliary variable, enhancing the quality and detail of the resulting maps. The basic climatic 'surfaces' generated in the interpolation process are then combined through various models, resulting in a range of maps that are useful for guiding crop diversification. Examples of such applied climatic themes include potential evapotranspiration, frost-free period, growing period, biomass productivity indices and similarity maps. Future directions and challenges are outlined, particularly with respect to agroecological zoning and land suitability evaluation.

INTRODUCTION

Central Asia and the Caucasus are two separate geographical entities, and are also very different in terms of agroecological conditions and land use systems. The Caucasus is essentially mountainous terrain with valleys that are cropped, usually under irrigation. Central Asia, on the other hand, is basically a huge plain bordered by mountains in the south. Most of this vast area is barren or sparsely

vegetated, used for extensive grazing, and contains large irrigated areas fed by rivers with their headwaters in the mountains. Rainfed crops are grown in the higher rainfall areas (Fig.1).

Since the breakup of the Soviet Union in 1991, the land use systems of the region have been experiencing significant changes. Most of the huge State and Collective Farms, which were the mainstay of agricultural production during the Soviet era, were dismantled after 1991, and transformed into a mixture of production co-operatives, private farms and family farms.

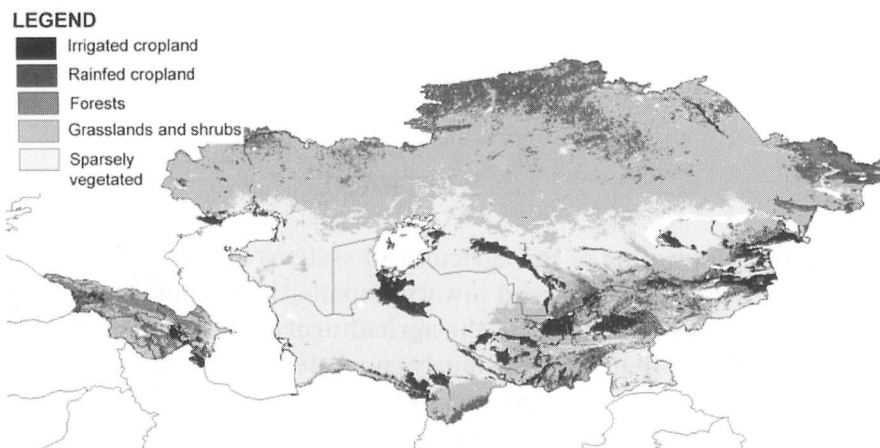


Fig. 1. Land use in Central Asia and the Caucasus.

In aggregate, the transformation of the agricultural sector has not been very successful. A major problem is that the Soviet-era, monolithic, large-scale production systems, based on cereals and livestock, often replicated themselves into co-operative farms instead of generating smaller, more flexible, market-responsive production units. The newly established farms are struggling to remain viable and have very low and often declining productivity for a variety of reasons, the main ones being (Dixon et al., 2000):

- Economic transition without a safety net to protect purchasing power.
- Loss of domestic and export markets.
- Lack of capital leading to deteriorating infrastructure for irrigation and capital equipment, fertilizer, pesticides and seeds.
- Lack of experience in competitive farming for markets.
- Lack of agro-processing facilities, distribution and access to markets
- Degradation of the natural resource base due to management practices and cropping patterns that are inappropriate for drylands.

NEED FOR AGROECOLOGICAL CHARACTERIZATION

In the centrally planned agricultural economy of the Soviet Union each eco-region produced a few crops, in accordance with its general climatic suitability, which were then distributed throughout the Soviet Union and eventually its regional market, the countries of the Council for Mutual Economic Assistance (COMECON). In addition, the land management units were of such extent that they required little knowledge about the climatic variations at small scales. In view of this regional specialization and the uniform management of large land areas, a broad eco-zoning was adequate to determine the suitability for pre-planned cropping patterns. Consequently, there was little need to have detailed maps of agroclimatic conditions.

With the collapse of trade within the former Soviet Union, the governments of the Central Asian and Caucasian republics found themselves in a situation where a higher priority had to be given to food self-sufficiency at national level and diversification of agricultural production. The transformation of previously collective farms into privatized farms has, in general, resulted into *smaller* land management units, which need to evolve into more *intensive* and *market-responsive systems* in order to survive and meet the needs of the urbanized areas.

To maintain or enhance productivity on these smaller farms, a better knowledge of the agricultural environments at a higher resolution is vital to guide diversification of land use and help agricultural research identify the right crops, cultivars and rotations for specific environments. Although the region is very *homogeneous in many areas, in others it has very diverse climatic conditions*. It is particularly in these regions with high ecological diversity that new opportunities for market-oriented crops and income generation may exist.

At the same time the region is characterized by major climatic constraints, particularly cold and drought, and these constraints will need to be addressed through a more effective targeting of new crops, varieties and technologies. Alternative rotations, appropriate soil and moisture conservation practices, and crop diversification have been repeatedly recommended as suitable management practices to improve agricultural productivity and farmer incomes. It is in this context that agroecological characterization is a key strategy for enhancing the productivity of the newly developing agricultural systems in the region and for increasing water-use efficiency.

PRIOR AGROCLIMATIC MAPPING

In the Soviet era, hydro-meteorological measurements were undertaken in a well-maintained network of stations. This network included about 400 stations for the whole of Central Asia and about 190 stations in the Caucasus. During the '80s

the network was in optimal condition (Chub, 2000). At the moment it is somewhat degraded (Table 1).

Table 1. Number of meteorological stations in the Central Asian Republics.

<u>Country</u>	<u>1980s</u>	<u>1998</u>	<u>Area per station</u> -10 ³ km ² -
Kyrgyzstan	95	62	2.1
Tajikistan	64	51	2.2
Turkmenistan	51	51	9.8
Uzbekistan	91	75	4.7
Southern Kazakhstan	64	41	
TOTAL	365	280	

Table 1 may be somewhat misleading. Although the average area covered per station is very large, station density is not a critical problem. The stations are very well distributed, with the highest number of stations in areas of high ecological diversity (especially the Caucasus), and a smaller, but regularly spaced, number in areas with small climatic gradients, like the interior lowlands of Central Asia (Fig. 2). Efforts are also underway towards station rehabilitation, particularly under international sponsorship, as part of the improvement of regional hydro-meteorological surveys. This assistance usually takes the form of provision of automated data-loggers and sensors, as well as facilities to allow remote communication.

More than actual data acquisition and availability, the major bottleneck is in the use of climatic data, owing to the slow progress towards computerization and limited (or expensive) public access rights. At the moment the major part of the climate data collection still resides in paper sources such as reference books (e.g., Geography Department of the Academy of Sciences of the Uzbek SSR, 1982), atlases, scientific publications, or even just as raw mimeographed data, stored in libraries.

On the basis of this climatic network, many climatic parameters have been mapped and are published in National Atlases, which exist for each country of Central Asia and the Caucasus. Figure 3 (Geography Department of the Academy of Sciences of the Uzbek SSR, 1982) provides an example of the thematic mapping that can be found in these atlases, and Table 2 gives a list of the most common climatic themes found in the country atlases.

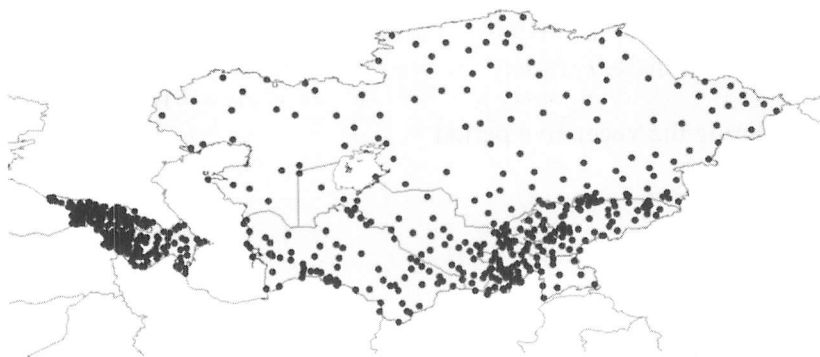


Fig. 2. Location of stations.



Fig. 3. Length of the frost-free period in Uzbekistan (scale 1:10,000,000).

The climatic maps in these Atlases are certainly useful for agriculture and some of the themes, such as those related to frost periods, have probably been underutilized as a tool for identifying new possible cropping patterns.

A major shortcoming is that the publication mapping scale was apparently set by the goal to have a more or less uniform atlas size for each country (roughly A3). The obvious consequence of this publication policy was that the detail of the published maps was significantly larger for smaller countries than for larger ones. Thus map scales vary between 1:1,500,000-3,000,000 in the Caucasus countries to 1:7,500,000-15,000,000 in the largest country (Kazakhstan).

Table 2. Climatic themes of the country atlases.

<u>Theme</u>	<u>Period</u>
Precipitation	Both
Precipitation during the vegetative period	Annual
Sunshine duration	Annual
Mean air temperature	Both
Air pressure	Both
Prevailing wind direction	Annual
Relative humidity	Monthly
Duration frost-free period	Annual
Temperature sums above 5°C, 10°C, 15°C	Annual
Temperature sums below 0°C	Annual
First autumn frost date	Annual
Last spring frost date	Annual
Number of days with maximum air temperature below 0°C	Annual
Number of days with maximum air temperature above 35°C	Annual
Spring date temperature rises above 5°C, 10°C, 15°C	Annual
Autumn date temperature drops below 15°C, 10°C, 5°C	Annual
Agroclimatic zones	Annual

Generally speaking, the combination of small mapping scales and broad boundary delineation makes the maps difficult to use for other than educational purposes. The climatic parameters are - with exceptions (e.g., frost-free periods) - not integrated into derived variables that would be of more practical value for agricultural land use planning. To guide the crop diversification efforts, higher-order integrated variables are required, such as waterbalance parameters, the length and time of the growing season, crop water requirements, or risk of climatic stresses (drought, high temperatures, frost).

Given the diverse climates, the stresses these impose, and the limited climatic stations, a major challenge in Central Asia is therefore to map these new agroclimatic variables at a scale that is sufficiently detailed to guide crop diversification within specific agricultural environments.

NEW APPROACH TO AGROECOLOGICAL CHARACTERIZATION IN CENTRAL ASIA

General Principles

Agroecological characterization is the description and interpretation of biophysical environments and associated land use systems for land use and

research planning. This characterization has to cover all relevant aspects of the biophysical environment, notably climatic and soil conditions, topography and water resources, as well as the associated land use systems. The characterization can be undertaken at different scales, in which case it requires different methods, datasets and spatial entities appropriate to each scale (De Pauw, 2003). At the macro-scale, climate and soil-landscape systems are the main sources of variation that affect suitability for different land uses and need therefore to be spatially represented. This paper discusses only the agroclimatic assessment of the whole region.

It is now possible to create computer-generated maps of individual climatic parameters, directly obtained from meteorological stations, that are more accurate than the existing Atlas maps and — of particular importance in mountainous terrain — take better account of topography as a factor that influences climatic conditions. These maps can be combined in a GIS-system to produce, through modeling techniques, new maps of derived agroclimatic variables, which are more useful for land use, water and crop management recommendations.

The general approach is to spatialize point climatic data using an appropriate interpolation method. Methods for spatial interpolation may be described as either 'global' or 'local'. Global interpolation methods derive a surface model by considering all the data points at once. The resulting surface gives a "best fit" for the entire sample data set, but may provide a very poor fit in particular locations. A local interpolator, on the other hand, calculates new values for unknown pixels by using the values of known pixels that are nearby (Eastman, 2001). For the purpose of downscaling to specific environments, local interpolators are more suitable than global ones, because they take better the underlying variability into account, which is exactly the purpose of downscaling.

Of the local interpolation methods, co-kriging (e.g., Bogaert et al., 1995) and co-splining methods (e.g., Hutchinson and Corbett, 1995) have been found particularly suitable for the generation of 'climate surfaces' from point data at representative locations. Climate surfaces are raster maps in which climatic variables are presented as continuous 'fields'. These fields provide an estimate of the climatic parameter for each point in a regular grid at a given resolution, on the basis of the statistical model used. The generation of climatic maps using either co-kriging or co-splining methods is based on the use of terrain variables as auxiliary variables in the interpolation process. In contrast to the climatic target variables themselves, which are only known for a limited number of sample points, terrain variables have the advantage to be known for all locations in between. In addition, some climatic variables, such as temperature and precipitation, are highly correlated with elevation, which increases the precision of the interpolated values significantly (De Pauw et al., 2000).

Terrain information is easy to obtain, in the form of topographical maps at different scales. These maps can be digitized and converted into digital elevation models (DEM) using standard GIS software. A DEM is essentially a regularly spaced grid which links for each grid cell location to altitude. From these models different terrain characteristics can be derived, such as slope, aspect, altitude, drainage, or roughness. Dedicated interpolation software, such as SURFER (Golden Software, 2002) or ANUSPLIN (Hutchinson, 2000) can use these DEM grid files as input to their interpolation methods.

The climate parameter surfaces, generated by the combination of point climatic data and terrain, in the form of a DEM, through an advanced spatial interpolation technique, can be combined in a GIS with other variables through dedicated models. Such integration allows generating spatially or temporally linked derived variables, such as soil moisture, runoff, crop water requirements, potential evapotranspiration, and others.

METHODOLOGY

A database was established of point climatic data covering monthly averages of the main climatic parameters (Table 3) for the stations in the Caucasus and Central Asia countries, covering the period 1950-85. These quality-controlled data were obtained from the Data Reference Books on Climate, which are available for each Soviet Republic.

Table 3. Agroclimatic variables and number of stations recording observations.

<u>Country</u>	<u>Precipitation</u>	<u>Temperature</u>		<u>Radiation/ Sunshine</u>	<u>Air Humidity</u>	<u>Wind Speed</u>
		<u>Maximum</u>	<u>Minimum</u>			
Armenia	50	50	49	20	50	47
Azerbaijan	50	50	50	21	48	45
Georgia	89	90	89	27	89	87
<i>Caucasus</i>	<i>189</i>	<i>190</i>	<i>188</i>	<i>68</i>	<i>187</i>	<i>179</i>
Kazakhstan	123	123	123	15	122	122
Kyrgyzstan	69	68	69	18	67	68
Tajikistan	64	63	60	16	60	60
Turkmenistan	75	71	72	25	59	58
Uzbekistan	65	50	50	7	36	38
<i>Central Asia</i>	<i>396</i>	<i>375</i>	<i>374</i>	<i>81</i>	<i>344</i>	<i>346</i>
TOTALS	585	565	562	149	531	525

The 'thin-plate smoothing spline' method of Hutchinson (1995), as implemented in the ANUSPLIN software (Hutchinson, 2000), was used to convert this point database into climate surfaces. This is a smoothing interpolation technique in which the degree of smoothness of the fitted function is determined automatically from the data by minimizing a measure of the predictive error of the fitted surface, as given by the generalized cross-validation (GCV). The GCV is calculated by removing each data point and calculating the residual from the omitted data point of a surface fitted to all other data points using the same smoothing parameter value. The GCV is then a suitably weighted sum of the squares of these residuals and can be approximated (Hutchinson, 2000) as:

$$\text{GCV} = \text{MSE} + \sigma^2$$

with MSE the mean square error of the fitted function, and σ^2 the error variance.

Three independent spline variables were used, *latitude*, *longitude* and *altitude*. The latter was input to the model in the form of a DEM ASCII grid file. The DEM used to generate the climate surfaces was GTOPO30, a global DEM with 30 arc-second (approximately 1 km) resolution (Gesch and Larson, 1996). Parameter estimation was undertaken over a regular grid with the same dimensions and resolution as the user-provided DEM. In order to automate the process of climate surface generation, which is rather cumbersome, an auxiliary software product CLIMAP was developed (Pertziger and De Pauw, 2002). This Excel-based software provides a user-friendly interface for running ANUSPLIN and for generating derived surfaces using CLIMAP-provided models.

RESULTS

Basic Climate Surfaces

Using the above procedure, surfaces of mean monthly precipitation, minimum and maximum temperature, sunshine hours, relative humidity and wind speed with 30 arc-second resolution were generated. An example is given in Figure. 4., which shows for the Caucasus countries the average maximum temperature in July, draped over a hill-shaded representation of the terrain.

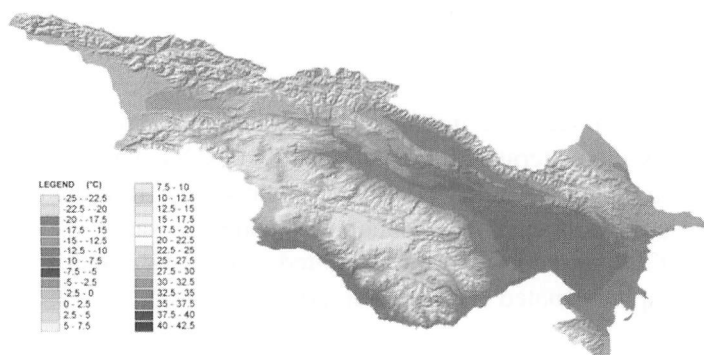


Fig. 4. Example of a basic climate surface: average maximum temperature in July in the Caucasus countries.

Derived Climate Surfaces

The basic climatic layers are the building blocks for generating new layers. A list of derived climate themes generated for the more in-depth agroclimatic characterization of the CAC countries is given in Table 4. The operations used to generate new layers can be elementary grid calculations on the existing basic climatic layers, which can in most cases be handled in standard GIS software without explicit programming. In other cases, a pre-programmed model needs to be provided. In all cases, the layers of interpolated basic climatic variables are processed according to the model's specifications, instead of first processing the climatic variables from individual stations, and then interpolating the new variables.

The models can be straightforward formulas that operate on the same grid cells without spatial or temporal linkage. An example of such relatively simple model is the one used to calculate potential evapotranspiration (PET) according to the Penman-Monteith method (Allen et al., 1998). This procedure, which is of critical importance to generate a number of agroclimatic themes, combines *temperature* (Tmax and Tmin), *sunshine* (Sunsh), *air humidity* (RH), and *wind speed* (Wind) as input themes. The procedure to calculate a PET layer from layers of basic climatic variables is represented in Figure. 5. Other agroclimatic themes can be generated in the same way by arithmetic or logical operations on individual layers, for example the aridity index is the ratio of annual Potential Evapotranspiration (PET) over annual precipitation (UNESCO, 1979). The Agroclimatic Zones theme in Table 4 is generated by the combination of moisture regime, and winter and summer temperature regimes as per thresholds developed by UNESCO (1979).

Table 4. Derived climate themes.

Theme	Monthly/Season	State
Potential evapotranspiration (Penman-Monteith)	Both	Static
Aridity index	Annual	Static
Agroclimatic zones	Annual	Static
Growing-degree-days below 0°C	Both	Static
Growing-degree-days above user-set temperature threshold	Both	Static
Frost days and frost-free days	Both	Static
Onset and end of frost-free period	Annual	Static
<i>Growing period</i>		
• Type	Annual	Static
• Onset, end and length of moisture-limited growing period	Annual	Static
• Onset, end and length of temperature-limited growing period	Annual	Static
• Onset, end and length of temperature-and moisture limited GP	Annual	Static
<i>Biomass productivity index</i>		
• Crop group I (C3 plants)	Annual	Static
• Crop group II (C3 plants for warm conditions)	Annual	Static
• Crop group III (C4 plants)	Annual	Static
• Crop group IV (C4 plants for cool conditions)	Annual	Static
• Vegetation productivity index	Annual	Static
Climatic similarity	Annual	Dynamic

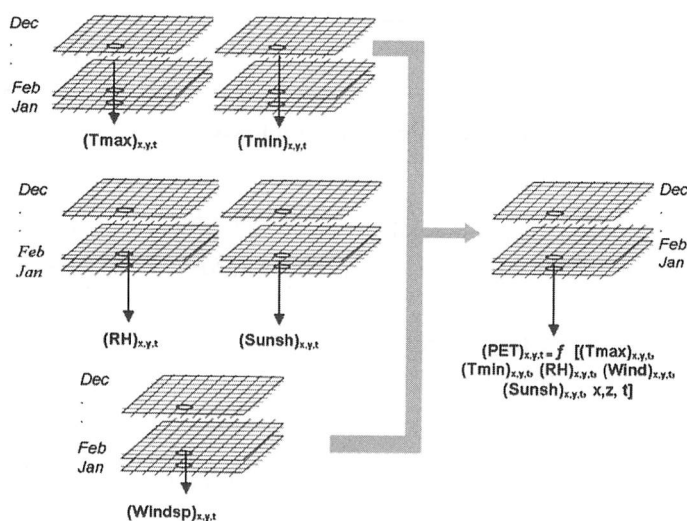


Fig. 5. Procedure for generating PET layers from basic climate elements layers.

Models based on regression allow using proxy variables in cases where the theme of interest cannot be represented directly due to data limitations. An example of a regression model is the one used to estimate the length of the frost-free period on the basis of the minimum temperature in each month: with P : frost-free period (in days per year); D_i the number of days in each month, and T_{min} : the minimum temperature for the month. The resulting map in Figure. 6 for Uzbekistan can be compared with the older map in Figure 3.

$$P = \sum_{i=1}^{12} D_i \left(1 - \frac{1}{1 + e^{-0.4261 - 0.446 T_{min}}} \right) \quad (r^2=0.95)$$

Growing Period and Biomass Productivity Mapping

In other cases, models with spatial or temporal linkage can be provided. An example of a simple model with temporal linkage is the model developed by the Food and Agriculture Organization of the United Nations (FAO, 1978) to estimate the length of growing period under either moisture-limiting or temperature-limiting conditions, or both.

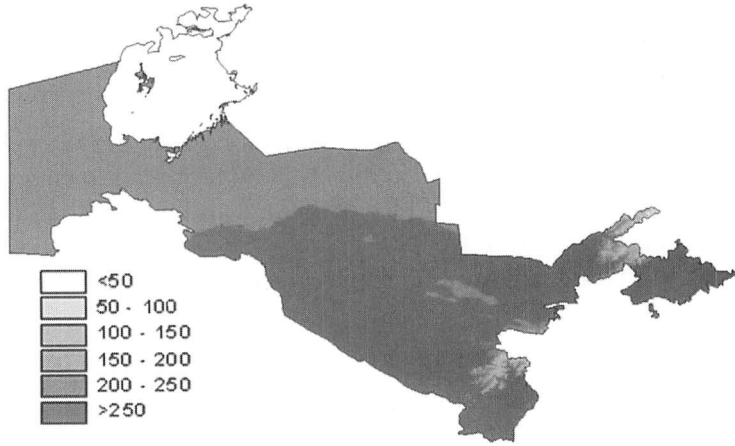


Fig. 6. Length of the frost-free period in Uzbekistan based on the minimum temperature.

The criterion used for the definition of a moisture-limited growing period is the ratio of actual evapotranspiration (AET) to potential evapotranspiration. If this ratio for any particular month is higher than a user-defined threshold (in this study, 0.5), that month is part of a growing period; if it is not, that month is not part of the growing period. The start date of the growing period is obtained from linear interpolation of the AET/PET ratios between the last month that is part of the growing period, and the first month that is not part of the growing period. The end date, inversely, is obtained by linear interpolation of the AET/PET ratios between the last month that is part of the growing period, and the first one that is not part of the growing period.

The following model for estimating the length of the moisture-limited growing period is an adaptation of the FAO-model.

$$GP_ON = M_Start + NDays \frac{Thre - R_0}{R_1 - R_0}$$

$$GP_END = M_End + NDays 2 \frac{Thre - R_{n-1}}{R_n - R_{n-1}}$$

$$LGP = GP_END - GP_ON$$

with: GP_ON: growing period onset date
 GP_END: growing period end date
 LGP: length of growing period
 M_Start: the number of days from 1 January up to the end of the last

month that is not part of the growing period
M_End: the number of days from 1 January up to the end of the month preceding the last month of the growing period
NDays: number of days in the first month of the growing period
NDays2: number of days in the last month of the growing period
Thre: AET/PET threshold for defining a growing period (user-defined; for this study set to 0.5)
R₀: AET/PET ratio for the month preceding the first month of the growing period;
R₁: AET/PET ratio for the first month of the growing period;
R_{n-1}: AET/PET ratio for the month preceding the last month of the growing period;
R_n: AET/PET ratio for the last month of the growing period.

By combining the moisture-limited growing period with a temperature-limited growing period, obtained by removing those parts of the year below a user-defined temperature threshold considered unfit for biological activity, maps can be made of the length of growing period, limited by both moisture and temperature. The map in Figure. 7 is indicative of the remarkable climatic diversity of the Caucasus countries.

It has been demonstrated (e.g., FAO, 1978; Fischer et al., 2000) that the climatic growing period is a suitable indicator of potential biomass productivity. Biomass productivity indices, based solely on growing period characteristics, can be used as exploratory tools to assess in which parts of the region different crop types have a comparative advantage under either rainfed or irrigated conditions. The biomass productivity indices listed in Table 4 are based on the concept of *accumulated temperature* as a proxy of radiation energy available for photosynthesis. The accumulation of temperature units only occurs within the growing

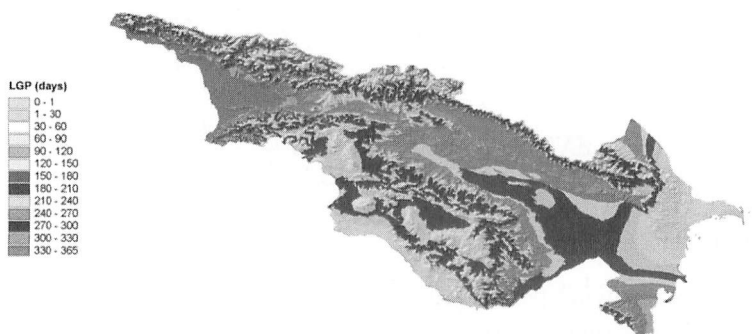


Fig. 7. Length of the temperature- and moisture-limited growing period (LGP) in the Caucasus countries.

period and is weighted according to the distance of the real daytime temperature from the optimal daytime temperature for each crop group:

$$CBPI_j = \sum_{i=GP_ON}^{GP_END} (ATI)_{i,j}$$

with: CBPI: crop biomass productivity index
j: crop group
i: day number
ATI: adjusted thermal increment (°C) for each day inside the growing period
GP_ON: growing period onset date
GP_END: growing period end date

In this model, the ATI depends on the daytime temperature and is:

ATI = 0	[Tday ≤ T0 or Tday ≥ Tx]
ATI = Tday - T0	[Tday > T0 and Tday < Topt1]
ATI = (Topt1 + Topt2)/2 - T0	[Tday ≥ Topt1 and Tday ≤ Topt2]
ATI = Tx - Tday	[Tday > Topt2 and Tday < Tx]

with T₀ : the daytime temperature below which no assimilation takes place (cold-limited);
T_{opt1} : the lower daytime temperature threshold above which maximum assimilation takes place;
T_{opt2} : the higher daytime temperature threshold above which assimilation rate declines;
T_x : the day-time temperature above which no assimilation takes place (heat-limited)

The temperature thresholds T0, Topt1, Topt2, and Tx depend on the particular crop group as shown in Table 5.

The value of these biomass productivity indices is that they can be derived from simple climatic data, allow out-scaling of productivity measurements at specific sites and have precursory use in land suitability assessment. It has to be realized that they provide a measure of *potential* productivity, not of current productivity, and therefore do not consider management factors, such as overgrazing, etc. Figure. 8 gives an idea about the comparative advantage for C3 and C4 plants in the Caucasus.

Table 5. Adaptability to temperature for different crop groups.

Crop Group	T_0	T_{opt1}	T_{opt2}	T_x
I (C3 plants)	5	15	20	33
II (C3 plants for warm conditions)	10	25	30	45
III (C4 plants)	15	25	35	50
IV (C4 plants for cool conditions)	10	20	30	45

(adapted from FAO, 1978).

Mapping Climatic Similarity

In similarity analysis, the value of a climatic parameter or index at one location (the 'match' location) is compared with other ('target') locations in order to quantify the degree of similarity in climatic conditions. Mapping similarity by means of *similarity indices* therefore offers the possibility of identifying target environments with good potential for introducing crops or cultivars that are doing well at a particular match location. As similarity depends on the climatic characteristics of the match location, a new map is created when this location changes, hence the term 'dynamic' mapping used in Table 3.

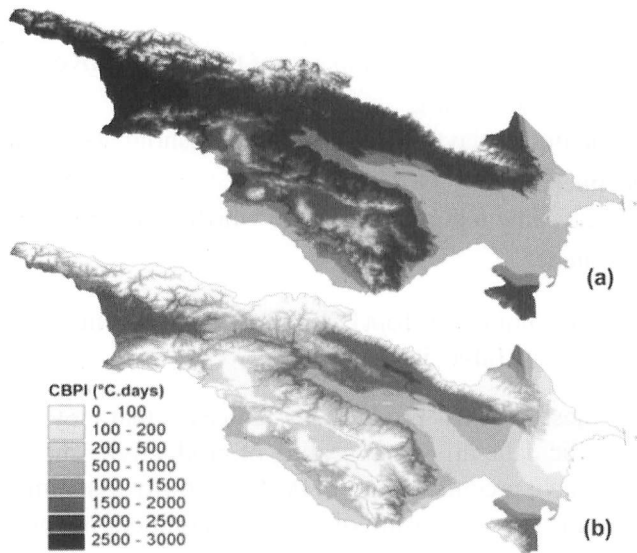


Fig. 8. Biomass productivity index for C3 plants (a) and C4 plants (b) in the Caucasus countries.

The model used to assess similarity is a very simple distance function:

$$S = I_{1(\Delta_t)} * I_{2(\Delta_p)}$$

The functions I_1 and I_2 are *similarity indices* for air temperature and precipitation respectively. They model the drop in similarity under increasing dissimilarity for air temperature Δ_t and precipitation Δ_p , respectively, as

$$I_1 = e^{\left(-\frac{\Delta_t}{\sigma_t}\right)} \text{ and } I_2 = e^{\left(-\frac{\Delta_p}{10 \times \sigma_p}\right)},$$

with σ_t [$^{\circ}\text{C}^{-1}$] and σ_p [mm^{-1}] user-defined calibration constants.

Data input is in the form of climatic grids (12 mean monthly precipitation and average temperature surfaces) for both match and target areas. The dissimilarity in temperature Δ_t is computed as follows:

$$\Delta_t = \sqrt{\frac{\sum_{i=1}^{12} (t_{i+s} - T_i)^2}{12}},$$

where i is month number, t is mean monthly air temperature in the target point, T is mean monthly air temperature in the matching point (OC), s is a phase shift in month numbering.

The phase minimizes the deviation in temperature between match and target location and is obtained by shifting the temperature array until the covariance:

$$\text{Cov}(\overline{T_m}, \overline{T}) = \sum_{i=1}^{12} (T_{m_i} - \overline{T_m}) \cdot (T_i - \overline{T})$$

reaches a maximum. In this way the seasonal pattern in different geographic locations can be synchronized. In a climatically homogeneous region the phase is 0. The maximum possible phase is 11. The same phase (s) is then applied to calculate the dissimilarity in precipitation pattern (Δ_p):

$$\Delta_p = \sqrt{\frac{\sum_{i=1}^{12} (p_{i+s} - P_i)^2}{12}},$$

where p is monthly precipitation in each target point, P monthly precipitation in the match point.

Fig. 9 shows similarity decay functions for temperature under different values for σ_t . The use of these calibration factors allows adjustment of the sensitivity to a particular climatic parameter. For example, a calibration factor 0.5 corresponds with an extremely high sensitivity to temperature: a difference of 1°C is sufficient to make the similarity index drop to about 2% (Fig. 9).

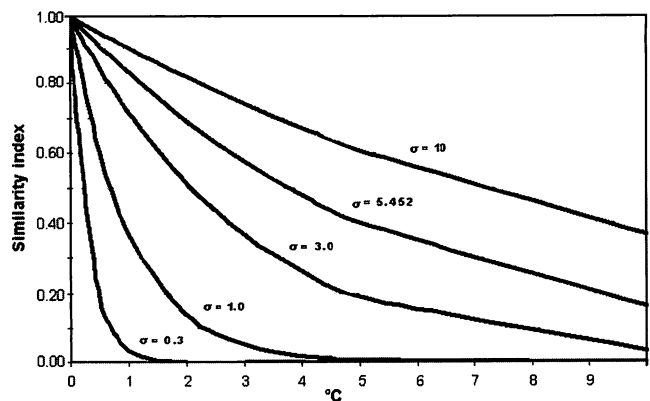


Fig. 9. Use of calibration factors to adjust sensitivity to a climatic parameter.

Fig.10 provides an example of similarity maps produced using the above model, with a few stations in the Caucasus as match locations and with Central Asia as target area. In the top map, the match location is Baku, Azerbaijan (40.32 N, 49.82 E, 7 m elevation), the bottom map the match location is Yerevan, Armenia (40.21 N, 44.53 E, 1278 m elevation). In this particular example, the calibration factor for air temperature σ_t is set to 5.455 and for precipitation σ_p to 2.9. The former corresponds to a similarity drop by 30% under $\Delta_t = 2^\circ\text{C}$, the latter to a drop of 50% under $\Delta_p = 20\text{ mm}$. The resulting similarity maps are the product of multiplying the two similarity indices following Liebig's Law of the Minimum.

FUTURE DIRECTIONS AND CHALLENGES

The methods and outputs discussed in previous sections are intermediate steps towards a more comprehensive agroecological characterization of the Caucasus and Central Asia. For the effective targeting of new crops, varieties and technologies within such a vast region agroecological zoning and land suitability evaluation are considered very useful research approaches.

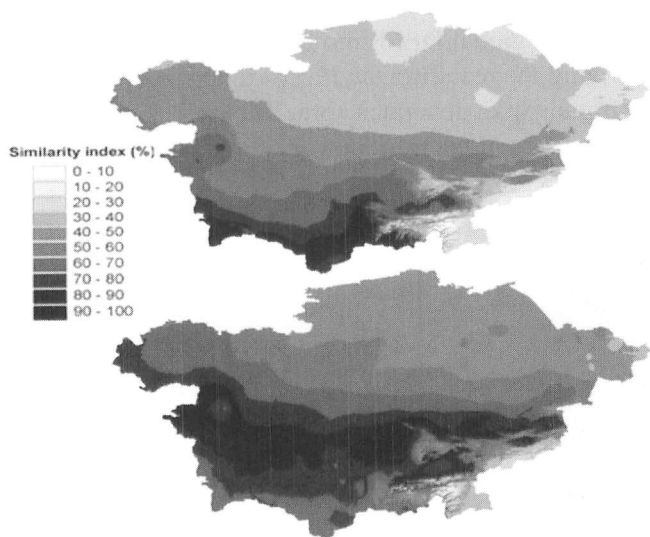


Fig. 10. Similarity in temperature and precipitation patterns between Central Asia and two stations in the Caucasus: Baku, Azerbaijan (top) and Yerevan, Armenia (bottom).

Agroecological Zoning

The first need is to prepare for the region *high-resolution maps of agroecological zones*, areas that are more or less homogenous in climatic, terrain and soil conditions. This should not be confused with the output from the Global AEZ study (Fischer et al., 2000), which is, in fact, a set of land suitability maps for major crops at global scale.

A map of agroecological zones is a useful starting point for defining the extrapolation domain of site-specific agricultural research in the region and allows, at the same time, to identify important agroecosystems that are not well covered by agricultural research stations.

Whereas in the past the manual integration of data from different disciplines was problematic, GIS overlay capabilities make it now perfectly feasible to combine climatic data with terrain and soil information. Preliminary research at ICARDA (De Pauw et al., 2002) has indicated that agroecological zones can be easily defined by the combination of terrain (DEM), climatic, soil and other data using GIS procedures.

The datasets are integrated in a stepwise procedure using two 'independent' biophysical frameworks, an agroclimatic and land systems framework. Each framework is characterized separately through its own specific attributes. The first framework is established through the spatialization methods developed in this

paper. The second framework is developed by converting either the global DEM GTOP030 or a suitable regional DEM into landforms using standard GIS operations, and characterizing the resulting landforms in terms of soil patterns. The merger of the two frameworks generates agroecological zones, which automatically inherit the characteristics of each framework (Fig. 11).

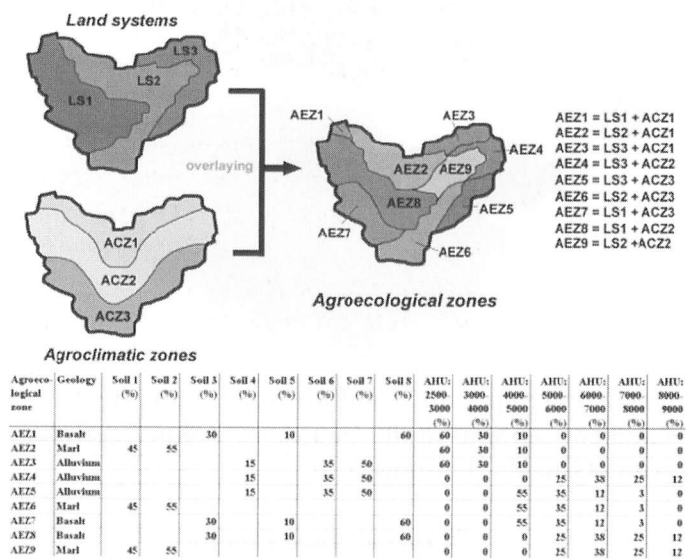


Fig. 11. Establishing agroecological zones through overlaying with a sample-attribute table.

Land Suitability Evaluation

Land suitability evaluation is the process of assessing the suitability of land for specified kinds of use (Dent and Young, 1981). The methods are based on the matching of the requirements of crops or specified kinds of use with characteristics of land that are relevant to their productivity. The classical approach is to develop application-specific land evaluation models, which are essentially decision-tree algorithms that match requirements to land characteristics. There are several challenges in using land suitability evaluation methods towards the goal of assisting crop diversification in Central Asia and the Caucasus.

A major problem for the application of land evaluation methods is that the ecological requirements of many plants are either poorly documented, scattered across multiple disciplines, within the sphere of informal knowledge, or the common denominator for a wide range of varieties with often different responses to critical environmental characteristics. For this reason, crop requirement tables

(e.g., Sys et al., 1993) are often based on an expert consensus about a subset of run-of-the-mill cultivars, which does not necessarily take into consideration the possibilities of crop breeding to extend the ecological requirements of crops targeted to high-stress environments.

In a drive towards crop diversification, relatively little-known crops, including those indigenous to the region, need to be included in the land suitability evaluation. These, as well as tree crops, often have poorly-documented requirements and the consequent need to transfer local knowledge into spatial information will offer particular challenges to GIS specialists.

The scale of a particular study always has implications for the kind of land evaluation models and databases that can be used. Inevitably, land evaluation models at the regional scale have to pay more attention to characteristics with regional dimension, such as those related to climate, rather than to terrain and soil differences which become more prominent at local level. This may limit the practicality of using deterministic crop simulation models, based on a physiological engine (e.g., DSSAT, CROPSYST, WOFOST) to relatively small areas with adequate environmental and crop databases for model validation. In essence, the larger the area to be covered, the more simple the land evaluation models and datasets should be for consistency and reliability. *The challenge will thus be to capture the main components of the environment that have the highest impact on productivity and stress with as simple and easily obtainable data as possible.*

CONCLUSIONS

During the Soviet era considerable work has been done to characterize the environments of Central Asia and the Caucasus. This information is no longer adequate to assist the current drive towards crop diversification in the region. This paper discusses the geospatial research tools, databases and methodologies developed by ICARDA for a better targeting of new crops, cultivars and technologies, as well as some intermediate results in the ongoing ecoregional characterization. The logical outcome of this research is a spatial information system that will provide answers to scientists, planners and development agents on the expected performance of new crops, cultivars and rotations in different parts of the region.

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Water Resources in Central Asia: Current Constraints and Development Potential

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ABSTRACT

The manner in which water resources in the Former Soviet Union were managed in the second half of the past century had both positive and negative effects. On one hand, extensive development in irrigation led to the conversion of millions of hectares of virgin lands to productive agriculture, *providing millions of people with food and livelihoods*. On the other hand, over-exploitation of water and natural resources led to dramatic changes in the environment, having *serious negative impacts on the area's human health and economy*.

Created in 1992 after the collapse of the former Soviet Union by governments of the five Central Asian States (Kyrgyzstan, Kazakhstan, Uzbekistan, Tajikistan, and Turkmenistan), the International Commission for Water Coordination is effectively organizing management activities of the States for sharing of the water from the Amu-Darya and Syr-Darya rivers, through each river Basin Water Organization. Planning of the annual activity of each organization is closely connected to water released from reservoirs for two competing uses - *irrigation and energy*. Future development of the region needs to meet the growth of population and demand for food and water of users and all sectors, to foster the economic development of the countries, as well as to *minimize the impacts on water quality and land degradation*. The issues involved in managing the water resources within the basin are complex and largely of an institutional nature.

All Central Asian states are undergoing water and land reforms initiated during the last decade. The reforms are related to application of innovative technologies, methodologies or techniques, adoption of new legal and regulatory instruments, but primarily to organizational changes for operation and maintenance of on-farm water management, and/or a combination thereof.

The States find themselves at different stages of institutional and economic development, as they proceed with various reforms, attempting to improve the management of scarce water resources, conserve water, and aid in restoring the ecology. Some of the reforms have addressed devolution of responsibilities to the lower level of the system, collective action, and more democratic processes for irrigation water management and, as a result, formation of Water Users Associations; good examples of such can be found in Fergana Valley.

However, to make sustainable changes and improvements in water resources management, the governance of water resources management in the Aral Sea Basin will need to change and become compatible and harmonized amongst the States - as well as joint action of States undertaken towards the adoption of "integrated water resources management". In addition, broad participation of all users and stakeholders is needed to effectively improve water management at all levels, increase water, and land productivity to feed the ever-growing populations. Under a water-scarce future, the region's politicians and society as a whole need to mobilize forces to sustain the livelihoods and ecology in the region. This can be achieved only on the basis of a mutually prepared strategy for improved water management that can provide for environmental sustainability and adoption of water conservation measures and increase of water and land productivity.

INTRODUCTION

When we talk about water in Central Asia, what inevitably comes to mind is the Aral Sea Basin, comprising two remarkable river basins, the Amu-Darya and Syr-Darya, extending almost over 1.5 million km². The Aral Sea Basin is shared by five republics of the former Soviet Union: all of Uzbekistan and Tajikistan, southern Kyrgyzstan, southern Kazakhstan, and most of Turkmenistan. The Syr-Darya originates in the territory of Kyrgyzstan and flows through Tajikistan, Uzbekistan, and Kazakhstan into the Aral Sea. The Amu-Darya is primarily formed in the territory of Tajikistan, but also by a few water courses in Afghanistan (about 20% of the flow) and continues into the Aral Sea through Turkmenistan and Uzbekistan.

The Basin has three distinct ecological zones: *mountains*, *desert*, and the Aral Sea with its *deltas*. The Tian Shan and Pamir mountains have peaks over 7000 m and average annual precipitation range from 800 to 1600 mm. The lowlands - deserts of Kara-kum and Kyzyl-kum, covering most of the Basin area - have precipitation as low as 100 mm. The irrigated areas of both rivers together encompass 7.5 million hectares (Fig. 1).

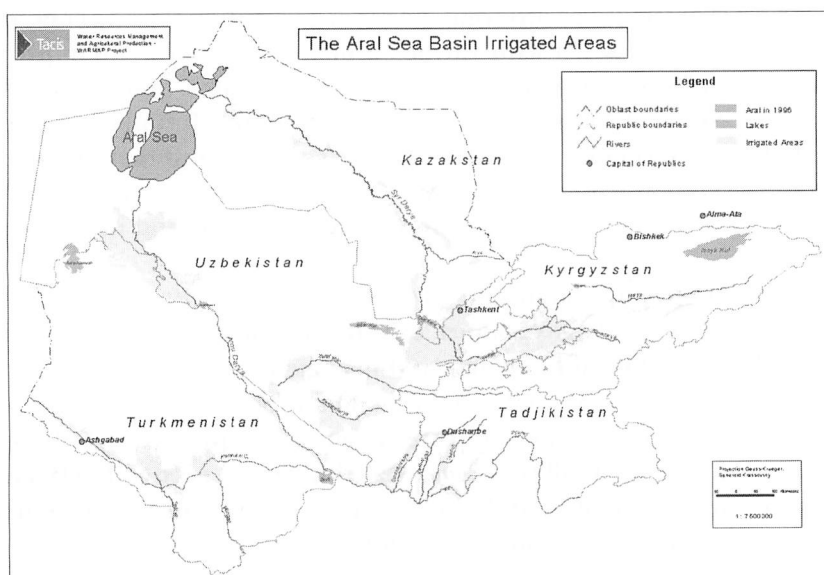


Fig. 1. The Aral Sea Basin.

The population of the Region has been steadily growing, with an average growth rate of about 2.54% (Kirmani and Le Moigne, 1997). Presently, the population is approximately 48 million, with Uzbekistan as the largest having 24 million, and Kazakhstan second with about 16 million.

The Aral Sea was the world's fourth largest inland lake in 1960, covering a surface area of about 66,100 km² with a maximum average depth of 68 m. By 1990, the inflows had substantially declined and in low-water years were approaching zero. As a result, by 2000 the Sea surface had shrunk by almost 40%, the maximum depth dropped by 14 m, and the salt content has dramatically increased from once being 11 g/L to over 30 g/L. Large areas of the Sea bottom became exposed and caused not only great economic losses to fisheries, but also social problems and drastic changes in the health of people and environment, negatively affecting the ecology chain.

For example, the entire tugai forests, as well as the muskrat population have been destroyed. The human living conditions were also deteriorating, giving rise to illnesses, especially of children, and subsequent population migration out of the delta areas. *The United Nations Environmental Program has stated that in terms of its ecological, economic, and social consequences the Aral Sea is one of the most staggering disasters of the twentieth century.* The prognosis for the future is gloomy, especially should the water management in the region continue with 'business as usual', as illustrated in the modeled scenarios from 1960 to 2020 (Dukhovny, 2002) as shown below.

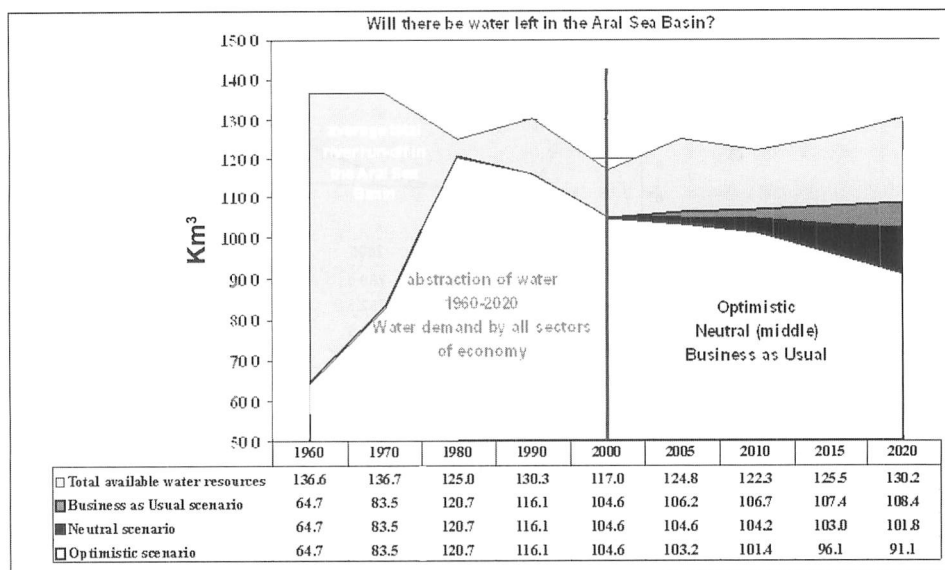


Fig. 2. Aral Sea - Where are we going?

Undoubtedly, there has to be readiness of the Governments to integrate relevant water policies and coordinate activities for better water management on the basis of public interest with the aim of achieving improvement of socio-economic development and environmental security. This can happen if there is a consensus amongst the States as to how the available resources will be planned and used, what will be the priorities, and what measures will be undertaken to safeguard and monitor the freshwater sources and vital ecological systems. Therefore, the States must resort to coordination of the relevant governance issues so that sustainable economic and social development in the region is achieved, and the negative impacts on soil and water systems are minimized.

Despite the fact that the five States' economic development is bound by water and that they historically shared patterns of development, each has its own path of transition towards democracy and the market economy system. As the States differ in terms of resource endowment, they also differ in the political and economic transformation. Some States like Tajikistan are in a very difficult economic situation, where the transition and five years of civil war has left its marks on the physical and social infrastructure (The Swiss Regional Mid-term Programme, 2002). Figure 3 below shows changes of the gross national product per capita for Uzbekistan for the last decade and gives options for three development scenarios (Dukhovny, 2002).

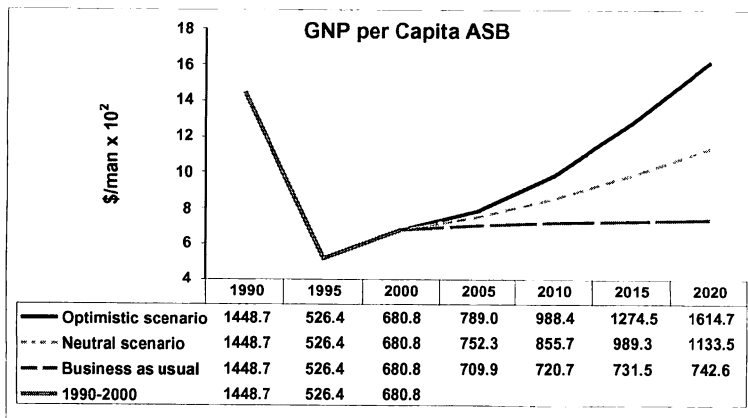


Fig. 3. Uzbekistan's average gross national product per capita.

Agricultural Water Use

Irrigated agriculture, consuming over 80% of available water resources of the Aral Sea Basin is clearly the largest water user in the region. Therefore, it also offers the greatest opportunity for water savings and water conservation. The critical aspects of water use and water conservation in agriculture are not only of a physical nature, but are primarily in the institutional system that manages the water resources and its governance. Up to the late eighties, the governments had planned, designed, operated, and maintained the irrigation schemes. After independence, *the main problems were related to the lack of funds to maintain and update the aging and inadequate infrastructure, coping with institutional inadequacies such as absence of legal, regulatory or organizational framework to address changes due to land reforms and irrigation needs.*

The increased competition for water during the eighties between the users and all sectors of the economy, as well as the need for better control and distribution resulted in a creation of a Basin Water Organization for each river in 1986, having the main task of regulating the allocation of water between the riparian states (SIC-CWC, 1999). Furthermore, after each State became independent, better arrangements for water distribution between the States were needed. This led to the establishment of the Interstate Coordination Water Commission by the heads of the five States in 1992.

The following aspects are critical for irrigated agriculture and overall improvement of rural institutional development in Central Asia:

- Investments in water supply, irrigation systems, water storage, water measuring and distribution technology, and communication.
- Water allocation - from being a matter of political choice to participation of water users and stakeholders.

- Decentralization of services for water delivery, operation, and maintenance to the lowest possible level.
- Strategic and comprehensive planning for water resources use.
- Filling the gaps in the organizational aspects of operation and maintenance of the irrigation systems.

Currently, all five States are undergoing various agricultural, land and water reforms, and find themselves at different stages of progress. Nevertheless, at the policy level, the changes are rather happening slowly, as the entire process of a transition towards more rational water use and efficient water resources management needs to be well understood before it can be designed and harmonized, not only amongst the States but also within each State.

The key issues are trans-boundary compatibility in governing policies and laws at both the national level as well as international. Within the different privatization efforts and macroeconomic changes, the role, rights, and responsibilities of different players including the donor community, to mobilize science and technology to intensify agriculture and improve water productivity has become important. There is no doubt that once the agricultural sector in Afghanistan will be rehabilitated, the need for irrigation water will increase - and Afghanistan should become a partner in sharing of water of the Amu-Darya.

The International Commission for Water Coordination (ICWC), comprised of the highest water-sector officials of each State, meets quarterly (at the minimum) and discusses the Region's plans and problems with water supply and allocation to the states. Besides the controversial water - energy nexus and 'dividing the pie' of water between the upstream and downstream states, the ICWC agenda also contains aspects of setting a different course for management of the water resources within the region and changes from the traditional setting of water management based on the administrative districts to the management based on a hydrographic principle, including the need for strategic planning and "Integrated Water Resources Management" (IWRM).

Management and Development Needs

The concept of Integrated Water Resource management, arising as a response to the world water management problems (GWP, 2002), is acutely needed in the Central Asia region because the concept promotes, among other things, environmental security. Therefore, a successful approach towards IWRM seems crucial, thus reducing major water problems experienced by the Central Asian States, such as:

- Rising demand for food, with less water available for agriculture.
- Rising competition between agriculture and other water sub-sectors (e.g., hydropower) for increasingly scarce water supplies.

- Inadequate access to safe drinking water and sanitation facilities.
- Inadequate or obsolete infrastructure.
- Low income and employment opportunities due to inadequate water supply.
- Low productivity of water.
- Declining water quality and environment-soil degradation, waterlogging, salinity.
- Territorial interests.

A common theme that is underlying the above-listed problems is *fragmentation of management and lack of appropriate policies*. There is a disconnection between demand and supply, between water use sectors, between different human and environmental needs, between water quantity and quality and between policies and institutions (Vermillion, 2002).

The basic concept of IWRM involves coordination of strategic planning, development, allocation, and use and management of the available water resources and sources (including *groundwater, return drainage water, and waste water*), on the basis of hydrographic units, which are to be managed in a conjunctive manner to maximize the economic and social benefits and, at the same time, safeguard the environment. This ought to be realized by applying new techniques and technological innovations, while minimizing negative impacts like waterlogging, land degradation due to irrigation with water of high salinity, and secondary salinization, without compromising the sustainability of vital ecosystems.

Participation of stakeholders in the processes of planning and development of policies and laws to manage water resources is essential for successful adoption of IWRM principles. In irrigated agriculture, the principles of participatory irrigation management, while relying on international lessons, can be potentially successfully applied in Central Asia.

To achieve the IWRM within each State and the region will require a well-planned approach at the policy level and operational levels, both being initiated at a different level of hierarchy, but approved in a partnership with participation of stakeholders and users. That means that for policy development the process will be initiated at the top and, for the operational level of water management, at the bottom.

The overall goal of rural institutional development is to use, manage and protect natural resources efficiently and in a sustainable manner by: (i) improving living conditions and framework for the economy; (ii) developing capacity and capabilities in integrated water and natural resources management; (iii) supporting policy development for financially viable management systems; and (iv) prioritizing infrastructural improvements.

Reforms toward improved water management need to affect all levels of water management hierarchy for all sectors of the economy using water and proceed gradually toward realization of the IWRM. At the lower level of the management system, capacity building in a form of Water Users' Associations helps to promote participatory irrigation management and achieve higher water conservation. These also offer economic advantages to farmers who become members; they are an effective means for improving water and land productivity at the basin scale, and therefore can assist in institutionalizing integrated water and natural resources management (Horinkova and Abdulaev, 2002). They can also form a basic unit for conjunctive management of all available water sources, including marginal waters, and positively impacting on the environment. In addition, Water Users' Associations and their federation can become a viable partner with higher-level management entities and forge partnerships, as well as benefit regional peace initiatives, therefore adding to stabilization of the region.

Water Management: Tool for Peace and Harmony

The water sector represents a strategic domain for peace and harmony in the Central Asia region. Prudent management of the available water resources in the Aral Sea Basin can serve as an integral element for the prosperous development of the Central Asian States' economies. Therefore, integrated water resources management can become a tool to assist in development of civil society. It is essential that 'hydro-solidarity' amongst the States and harmonizing of local interests can positively enhance the development of the region's multi-ethnic society, and subsequently improve livelihoods and eliminate tensions and potential conflicts (Fig. 4).



Fig. 4. Major zones of tensions due to water diversions, storage, infrastructure and/or ethnic issues (Swiss Regional Mid-term Programme for Central Asia, 2000).

In overcoming the trans-boundary issues in water supply and allocation, IWRM can be achieved within both river basins through development of a compatible integrated policies framework, based and implemented under revised legislation and regulatory mechanisms, through a network of organizations that fulfill the necessary functions towards delivery of water services. In other words, under such a process new governance would be formulated that will plan, manage and optimize the use of available water resources and sources for multiple demands. Under this process the most negative aspects of soil and land degradation can be minimized by using appropriately all available research, modeling, data, and technology.

The sustainability of changes of transformation toward IWRM is enhanced by a participatory process that can be engaged at different levels of the management system. Not only users, but also key stakeholders should take part in discussing and approving the changes relevant to the proposed policies and legislation as well as operational and management changes relative to Water Users' Associations.

Water Conservation - a Strategy for Survival

Since the possibility of developing new lands for irrigation is very limited, the increase of land and water productivity seems to be a prime and effective means for future development. As elsewhere in the world, water conservation programs for Central Asian States will need to be incorporated in the national water strategies so that there would be water available for the demands by mankind and the environment. However, so far, there has not been enough consolidated efforts from the governments to embark on a regional or, for that matter, on national water strategies and comprehensive water use planning, although some measures such as water pricing and regulation (new Water Codes) have been adopted in some states (Kyrgyzstan, Tajikistan, Kazakhstan).

There has been some success in water conservation shown in a 'Best Practices' project executed in four countries of the region (Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan) in employing relatively simple and inexpensive measures at the field and farm level to save water. (The 2-year project has been funded by the International Water Management Institute (IWMI) as a continuation of WUF-MAS Project and a component of the WB-GEF, but expanded in scope to conduct more monitoring activities; it was executed jointly by IWMI, Scientific Irrigation Institute (SANIIRI), and the Scientific Information Center (SIC) of the ICWC. These measures, among other things, include minor repairs; equipping outlets with water accounting devices, soil surface leveling, shortening furrows, etc. In addition, organizational measures undertaken by the water-providing entities, such as water rotation, changes in cropping patterns and improved discipline of water distribution have also been shown to save water (Abdualev et al., 2002).

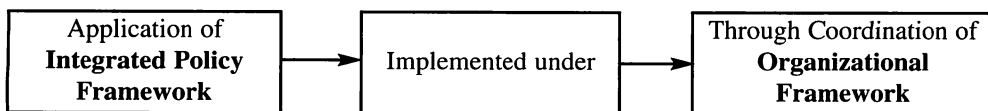
A combination of different measures can lead to 'real' water savings, where water saved can be transferred to another use. Important aspects are: (i) assessment of technical losses, (ii) reduction of management losses via establishment of Water Users' Associations, (iii) strict rotation, and (iv) water measurement. In addition, in order to save the water at a larger scale such as the basin, it may be necessary to focus on 'hydronomic' zones as a strategy towards increase of irrigation efficiency and beneficial water utilization (Molden et al., 2001). The problems and solutions need to be reflected in the policies for irrigated agriculture, so that water and land productivity can be increased. Policies also need to include a conceptual support for farmers/water users, such as extension services, because the newly emerging farmers have little or no experience and need help selecting irrigation methodology, norms, techniques, cropping pattern choice for specific soils, and agricultural technology.

REFORMS AND PILOTING THE PROCESS OF CHANGE

The process of changes towards IWRM may look relatively simple in theory, but it is difficult in practice, as the issues with water scarcity, deteriorated infrastructure, waterlogging and salinity, organizational gaps for water distribution and delivery, lack of unified social behavior, and strong territorial, and political interests are serious constraints that can only be resolved gradually, with good planning at the national and, especially, the regional level. In addition, the legacy of the former water management, complexity of laws and hierarchies, and institutional arrangements is a real challenge - and a paradigm not easily overcome. Therefore, the change-process towards more effective operation of the system usefully introduces participation of water users and stakeholders, to achieve a consensus in policy issues and management of the systems.

IWRM is intended to help to avert the water crisis that is faced by many countries and vividly looming in Central Asia. *The main challenges in Central Asia are institutional, although they need to be coupled with technical innovations.* The objectives for any water institutional development program need to be defined by each Government, as well as for the region, with the necessary commitments secured. Such a development program is influenced by political and social factors endemic to each situation and, importantly, includes the water-energy nexus.

To adopt the IWRM principles in Central Asia, gradual reforms in policies for planning, allocation, use, management, monitoring, inspection, database development, and research and development will be needed, in addition to changes in the supporting legal framework, following the basic tenet germane to IWRM (Horinkova, 2002). It can be described as:



As the governance affects the system at the top and bottom, changes at the top primarily constitute new policies, legal and regulatory framework and streamlining of functions to manage irrigation and drainage system, as well as changes in the administrative aspects, e.g., replacement of procedures with more transparent arrangements. At the bottom, the governance shapes the operational nature of the system and ought to achieve more economical and effective operation and maintenance of irrigation, drainage, and flood control and, primarily, effective delivery of services.

As an impetus to promote the concept of IWRM, an association of the Scientific Center of the ICWC and the International Water Management Institute is executing a project that tackles some of the organizational and technical issues that would be a step toward applying the principles of the IWRM in Ferghana Valley, a 3-year project funded by the Swiss Development Corporation. The Project covers three States - Kyrgyzstan, Tajikistan, and Uzbekistan, and involves participants at three water management levels: (i) Water Users' Associations; (ii) canal command body as basic hydraulic unit - in a short term; and (iii) the Basin Water Organization in the medium to long term. The Project also involves many stakeholders, and as such includes substantial capacity-building efforts. Notably, the technical improvements in automation and information technology are coupled with the institutional changes. Important for the initial phase of the Project, the support by the three governments was obtained.

As the changes in the pilot areas progress, experience will be gained and, hopefully, conclusion for recommendations to the policy-makers prepared, thus ensuring a smoother transition to the regional water management that would improve the overall socio-economic situation, secure rural livelihoods, and sustain environment for future generations.

The political support for IWRM is inevitable and needs an advocate and a champion at higher level of Government to succeed. *Reforms affecting either one nation or the entire region need to be properly planned, designed, and managed, with an accountability of leadership and collaboration of all parties and participation of stakeholders.* For any reform, the roles and tasks of organizations and individuals in the planning, implementing and monitoring need to be carefully assigned, and the process of change made transparent and approved by stakeholders.

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Development of Groundwater Salinity in a Region of the Lower Amu-Darya River, Khorezm, Uzbekistan

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ABSTRACT

The desiccation of the Aral Sea and shrinkage of its area have caused rapid environmental degradation within its Basin. The Khorezm region in Uzbekistan, located along the lower Amu-Darya River, is an intensively irrigated area. This paper investigates spatio-temporal variations of groundwater depth and salinity using information collected from 1987 groundwater monitoring wells.

The comparison of hydrographs reveals three clear temporal water consumption phases: 1) 1980-1987, high water consumption, with complete withdrawal of river water during the main irrigation season, 2) 1987-1995, relatively low water consumption after the collapse of the former Soviet Union; 3) 1995-2000, rapid increase in water consumption caused by economic reforms and agricultural diversification. Such water consumption patterns are well reflected in temporal changes in groundwater depth and salinity, which showed a rapid increase in the late 1990s.

The overall spatial distribution of groundwater salinity shows strong spatial association with parent materials and distance from the river along the main irrigation canals. Coarser parent materials showed higher groundwater salinity than finer parent materials. Groundwater salinity increased significantly with distance from the river along main irrigation canals. A change detection method revealed that highly saline groundwater zones have expanded progressively during the past decade from an already saline groundwater zone at the end of the main irrigation canals. The strong spatial heterogeneity of groundwater salinity variation calls for a more site-specific approach in water use in order to preserve local environmental conditions.

INTRODUCTION

The Aral Sea, once the world's fourth largest lake, has experienced rapid desiccation since the middle of the last century (Micklin, 1988; UNESCO, 2000). The surface water level dropped from 53.3 m in 1960 to less than 35 m in 2000. The average surface area shrunk to less than 25 km³, while the average water volume was about 200 km³ in 2000, which is only 20% of that in 1960 (Micklin and Williams, 1996). The results have been rapid economic and ecological degradation both in the Aral Sea and the surrounding environment (Wolff, 1996).

Enormous quantities of salts and chemicals have accumulated on the exposed Sea floor and have been transported to surrounding areas by an increasing number of storms (Razakov et al., 1996). Increasing river flow uncertainty and salinity together with inefficient land and water management have led to soil salinization in the areas around the Aral Sea Basin (Dukhovny et al., 2001). Biological productivity has sharply declined; 20 out of 24 native fish species have disappeared due to the decreasing water volume and accumulation of toxic elements. Subsequently, many fishing villages have been abandoned (Micklin, 1988). Drinking water problems related to increased salinity and pollution of river water are especially acute in densely populated areas. An increase in illnesses, particularly affecting children and pregnant women, has been reported (Elpiner, 1999).

Even though the Aral Sea has experienced several expansions and desiccations in historical time due to a combination of anthropogenic and climatic factors, it is widely believed that the current desiccation is mainly human-induced (Ivanov et al., 1996; Wolff, 1996; Glantz, 1999). Amu-Darya and Syr-Darya are the principal rivers flowing into the Sea. Before the 1960s, the average annual inflow from these rivers to the Sea was 63 km³; in the 1990s a dramatic decrease with only 5 km³/yr. was observed (UNESCO, 2000).

Such a negative trend in the water balance was coincident with the rapid increase in the irrigated areas in the Basin. The irrigation area in the Basin was 3.0 and 4.5 m ha in 1913 and 1960, respectively (Bortnik, 1999). The irrigated area then increased to 7 m ha in 1990 and to 7.9 m ha in 2000. The Aral Sea Basin is experiencing continuous population growth, with the need for producing more food on the one hand, and a continuous decrease of water availability and environmental problems associated with land and water resources on the other hand.

These problems have attracted increasing interest from the world research community. In collaboration with UNESCO, the Center for Development Research (ZEF), Bonn, launched a new research project supported by the German Ministry of Research and Education; see www.zef.de for further details). The objectives were to identify economically and ecologically sustainable land- and

water-use strategies in Khorezm, Uzbekistan, and to encourage local scientific and technological capacity-building. The Khorezm region is located about 223 km southeast of the Aral Sea, and one of the last water users of the Amu-Darya River together with neighboring Turkmenistan and Karakalpakstan. As an intensively irrigated "oasis" surrounded by deserts, its economic and ecological sustainability entirely depends on the water availability from the Amu-Darya. Considering the fact that the Karakalpakstan region, located further downstream, already suffers greatly from environmental degradation, the continuing desiccation of the Aral Sea will jeopardize the future sustainability of the Khorezm region (Vlek et al., 2001).

The Government of Uzbekistan maintains an intensive groundwater monitoring system throughout the Khorezm region, providing continuous records for both groundwater depth and salinity. As a heavily irrigated area, the distribution and quality of the groundwater in this region directly influence the soil moisture and salinity level, which subsequently determine agricultural food production and water availability (Nurmanov, 1966; Kats, 1976).

A detailed investigation of the spatial distribution and temporal dynamics of the groundwater will provide an insight in the current agro-ecological conditions and future sustainability of the Khorezm region. Under a bilateral collaboration agreement, the UNESCO/ZEF project coded and geo-referenced this information using a Geographic Information System.

This paper reports preliminary findings from the constructed spatio-temporal groundwater information system of Khorezm. The specific objectives of this paper are to: 1) identify the water availability and consumption patterns within the Khorezm region over the last two decades; 2) characterize the temporal changes in groundwater depth and salinity during the last decade or so; and 3) examine the changes in groundwater salinity over the same period.

STUDY AREA AND DATA

Khorezm: An "Oasis"

Khorezm is located in the northwestern part of Uzbekistan. It lies between 60.05 and 61.39° N and 41.13 and 42.02° E, and about 223 km southeast of the Aral Sea (Fig. 1). The climate is dry continental with a mean annual temperature of 12.1°C. Estimated annual evaporation is about 1626 mm, which far exceeds the annual rainfall of 79 mm. The topography is flat with elevations ranging from 112 to 138 m (Kats, 1976).

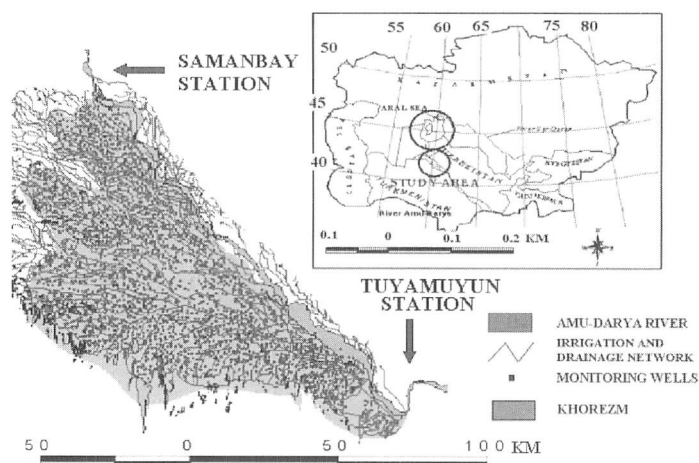


Fig. 1. Location of Khorezm and distribution of irrigation and drainage network and monitoring wells.

Khorezm has 1.3 m inhabitants, of which 80% live in rural areas (MMS, 2001). Population growth was about 2.8% from 1992 to 2001 (MMS, 2002). The region is surrounded by the Karakum and Kizilkum Deserts, and current economic activities solely rely on the irrigated water from the Amu-Darya River on the northeastern border. Irrigated areas covered about 49% of the total land area (562,192 ha) in 1990 (Fig. 1.). After independence, the irrigated areas have continued to expand from 253,000 ha in 1992 to 270,900 ha in 1995, and to 275,000 ha in 2000. The change of the irrigated areas from 1985 to 2000 was about 23%.

Four main and two feeding canals supply water from the River to the area through hierarchically structured irrigation canals. Temporary ditches are dug to supply water directly to the fields from the canals. The main method of irrigation is furrow. In 1997, Only 20% of the canals were lined. In 2000, drainage disposal constituted 70-75% of the irrigated water, with the estimated irrigation efficiency being 50-60% (GME, 2000). All drainage is directed towards the Sarikamish Depression located west of the region, which is no longer connected to the Aral Sea.

Due to its favorable topographical and climatic position, the Khorezm region was selected during Soviet times for the production of rice, in addition to cotton. In general, land and water management practices (irrigation and drainage infrastructure and its maintenance, crop varieties, etc.) were uniform throughout the region during Soviet times. Most of the agricultural land is still organized as State farms (*shirkats*) of about 1,500 - 2,000 ha in size, even though some agricultural

land has been distributed among private farmers (who lease the land for a period) and dekhkans (who own the land).

The irrigated area consists of alluvial soils, dominated by fine-grained sands with clayey, loamy and sandy loam sediments (Nurmanov, 1966; Kats, 1976). Soil-hydraulic characteristics show a strong horizontal and vertical heterogeneity with unique solute and water movement and retention properties. The whole area is salt-stressed; moderately to highly salt-affected areas already occupied about 50% of the area already in the 1970s (Kats, 1976). The practice of salt leaching (dilution and removal of salts by irrigated freshwater) has been widely used to remove salts from the topsoil before planting based on the recommendations of the Ministry of Melioration and Water Resources (1975).

River Water Discharge

Monthly-averaged discharge measurements of the Amu-Darya River were obtained from the Main Department of Hydrometcentre, Uzbekistan, covering the period 1980-2000. Data from two measurement stations were used in this study: the Tuyamuyun Measurement Station located on the Amu-Darya River before it enters the eastern border of the region, and the Samanbay Station on the western border with neighboring Karakalpakstan (Fig 1). The difference in the discharges between these two stations allowed for the assessment of relative water-use patterns in Khorezm, even though part of the water was also diverted to three districts in Karakalpakstan located on the right bank of the Amu-Darya River and a district immediately west of Khorezm. Water discharge (million m³) was measured by sounding leads with spinners that measure flow velocity at different depths.

Groundwater Depth and Salinity

Groundwater depth and salinity data were obtained from the Geohydrological-Melioration Expedition of the Khorezm Department of Agriculture and Water Resources, Uzbekistan. The data were collected from monitoring wells during the 1990 - 2000 period. These wells were evenly distributed over most of the area (Fig. 1). Metallic pipes with 90 - 110 mm inside diameter were used for well construction, perforated parts being located at different depths from the ground surface. Sand - gravel filters were used to prevent fine soil particles from clogging the perforated parts.

The depth of the groundwater table was measured every 5 days during the growing period; monthly-averaged data are used. The groundwater depth was measured using a tapeline with a cylinder that flaps when it reaches the water surface in the well. Groundwater salinity measurements were conducted three

times a year: April, July, and October. The water samples were analyzed for total dissolved solids (TDS) and chloride content; TDS measurements were used for this study.

The groundwater depth and salinity measurements recorded on paper were coded, and the location of each monitoring well was geo-positioned using a hand-held GPS (Garmin GPS 12, Garmin International, Inc.). The geo-positioned data were combined with the GIS layers. The GIS layers of the irrigation and drainage network in Khorezm were digitized from cartographic maps at a scale of 1:50,000 by the Design Institute "Uzgiplomeliiovdkhoz", Tashkent. The distribution of parent materials was obtained from the German Space Agency, i.e., DLR (Ressl, 1999). The digital map of parent materials is based on the map of scale 1:500,000 from the Russian Academy of Sciences.

Within the Khorezm region, there are nine topographical soil-textural zones (Fig. 5B). Representative soil properties of each zone were not available due to the complex nature of fluvial sediments, but the maps provide general soil textural classes whose spatial distribution shows a clear linear pattern along the Amu-Darya River. The distribution of textural classes is coarser from the river to the desert in the south due to the deposition of eolian sediments from the desert through seasonal winds (Vostokova, 1999).

The spatial distribution of groundwater depth and salinity was interpolated and mapped using a kriging function after detailed semivariogram analysis. Depth and salinity values were log-transformed prior to the geostatistical analyses. Semivariogram parameters were calculated in S-Plus 6.0 (MathSoft, 2000). These parameters were used to produce maps in ArcView 3.2 (ESRI, Inc).

RESULTS

Amu-Darya River Discharge: Temporal Variation

The quality and quantity of the Amu-Darya River water showed high seasonal variation. The sources of the Amu-Darya River are primarily snow and melting glaciers in the Tien Shan Mountains (Chembarisov et al., 1989). Precipitation within Khorezm only marginally influenced the discharge in spring. An increase in water runoff was usually observed in March with peaks in June-July; it was lowest in winter (Fig. 2). There was a strong negative correlation with the runoff and salinity level of the Amu-Darya River, directly determining the salinity levels of the irrigation water (Dukhovny et al., 2001).

The river water discharge at the Tuyamuyun Station showed a relatively stable water flow over the observed period. However, the hydrograph at the Samanbay Station revealed three clear temporal patterns 1) 1980-1987 (Phase I), with strong seasonal fluctuation of water discharge; 2) 1987-1995 (Phase II), with stable and

comparatively high water flow; and 3) 1995-2000 (Phase III), with a re-appearance of strong seasonal fluctuations and an overall decrease in discharge. Since these two measuring stations were located approximately at the entry and exit points of Khorezm along the river, a comparison of the hydrographs reflects relative water consumption within the Khorezm region.

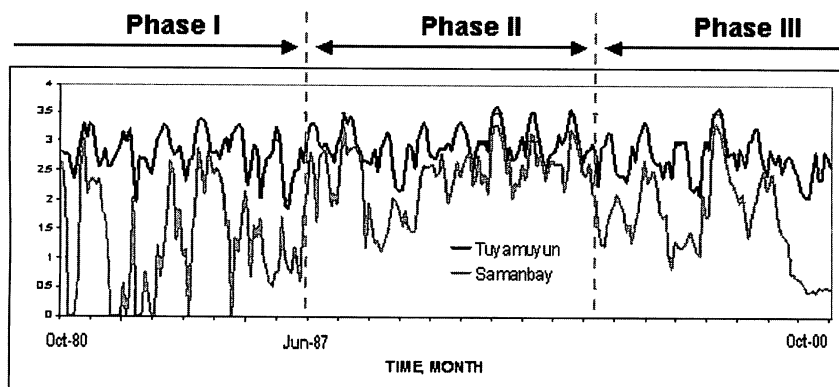


Fig. 2. Temporal variation of water discharge at two hydrological measurement stations. See Fig. 1 for the approximate location of the measurement stations.

The high water consumption for irrigation purposes was clear from the hydrograph readings taken before the late 1980s (Phase I). An especially dramatic situation was observed in the springtime of those years, when leaching combined with low river water discharge resulted in the complete diversion of water from the river, leaving downstream Karakalpakstan and the Aral Sea without water. A strong seasonality of water flow in Phase I should also be noted, with low readings in spring (March-May) at the Samanbay Station compared with the other two phases.

The Second Phase between 1987-1995 was characterized by a much higher water flow at the Samanbay Station, with a low seasonality. Unlike the two other periods, the hydrographs at both stations gave similar readings, indicating a relatively low withdrawal of river water in Khorezm. Further socio-economic studies are necessary, but it can already be hypothesized that socio-economic uncertainty and the consequent decline in agricultural activities during the disintegration of the former Soviet system were probably the reasons for the reduction in water consumption. The general decrease of water use during the disintegration of the Soviet Union has been reported in several Republics within the Basin (Dukhovny et al., 2001).

The Third Phase again showed a decreasing water discharge at the Samanbay Station, beginning around 1995. Though the withdrawal of river water was not severe compared to the period prior to 1990, an overall increase in water

consumption within Khorezm was obvious. This may have been due to the stabilization of the socio-economic conditions and the introduction of new agricultural policies in Khorezm, starting in 1994 (KDS, 2002).

A comparison of the hydrograph readings of the 1995 - 2000 period with those of the 1980 - 1987 period further suggests that water consumption was more evenly spread during Phase III. Though the period 1980-1987 was characterized by strong seasonal variation in the discharge at the Samanbay Station, such clear seasonality was no longer observed in the period 1995-2000. This is possibly due to the diversification of agricultural activities and crop varieties. Prior to 1990, the main crops in Khorezm were cotton and rice, but wheat was introduced as a State crop after 1994 with as much as 14,000 hectares (KDS, 2002). Furthermore, introducing a market economy has encouraged farmers to grow more diverse crops and vegetables. The transition from a monoculture crop production towards diversification of crops may lead to a water demand spread more evenly over the year.

Groundwater Depth and Salinity Temporal Dynamics

During the period 1990-2000, the average depth of the groundwater table was 1.47 m, ranging from 0.04 m to 5.55 m (Table 1). The depth to groundwater was 1.36 m in April and became shallower in the course of the growing period (1.28 m in July). The geohydrology of the area was characterized by a slow lateral groundwater flow due to low relief (Nurmanov, 1966; Kats, 1976). The groundwater table rises quickly in response to salt leaching and irrigation. At the end of the growing period, a groundwater decline was observed (1.82 m) as there is no water supply after the growing season and irrigation canals are usually closed for maintenance. A perched water table was often observed in the irrigated areas due to the hydraulic anisotropy caused by the stratigraphic nature of the fluvial-origin parent materials (Zholibekov, 1991; Mukhammadiev, 1982).

Table 1. Descriptive statistics of groundwater depth and salinity¹.

Month	Mean	Min	Max	SD	Skewness
----- Depth ² , cm -----					
April	136.6	6	555	45.2	0.93
July	125.1	4	456	46.6	1.02
October	181.7	6	500	55.3	0.27
Total	147.8	4	555	49.0	0.74
----- Salinity ² , g/L -----					
April	1.83	0.4	24.0	1.1	3.53
July	1.78	0.3	17.3	1.0	3.36
October	1.70	0.3	20.0	1.1	3.50
Total	1.77	0.3	24.0	1.1	3.46

¹ n=1987; ² Transform log10

Shallow groundwater contributes to salt accumulation through capillary rise, and results in the accumulation of salts at the soil surface (Nurmanov, 1966; Rhoades et al., 1992). In agricultural fields, the "critical depth", which results in the accumulation of salts due to capillary rise, is in the range 1.5-2.0 m below the surface (Dukhovny, 1996). Taking into account that the "critical depth" varies depending on soil texture, irrigation intensity and salinity level of soil and groundwater, the groundwater depth in Khorezm was above the critical level throughout the growing season.

During the study period, the average depth to the groundwater table showed a constant decrease until a drought year in 2000 (Fig.3A). The consistent rising of the groundwater table corresponded to the gradual increase in water consumption within Khorezm during this period (Phase II and III in Fig. 2). Due to the droughts in 2000 and 2001, the government imposed strong restrictions on water usage, which may have lowered the groundwater table. The fluctuations in groundwater depth clearly decreased through the years from growing to non-growing period (Fig. 3A). The difference between the shallower groundwater depth in April-July and a deeper groundwater depth in October gradually decreased by 0.45-0.57 m from the early 1990s until 2000. As observed through the comparison of the hydrographs (Fig. 2), the increase in water consumption in phase III and the more frequent irrigation events throughout the year could explain the decrease in seasonality in the groundwater fluctuation pattern.

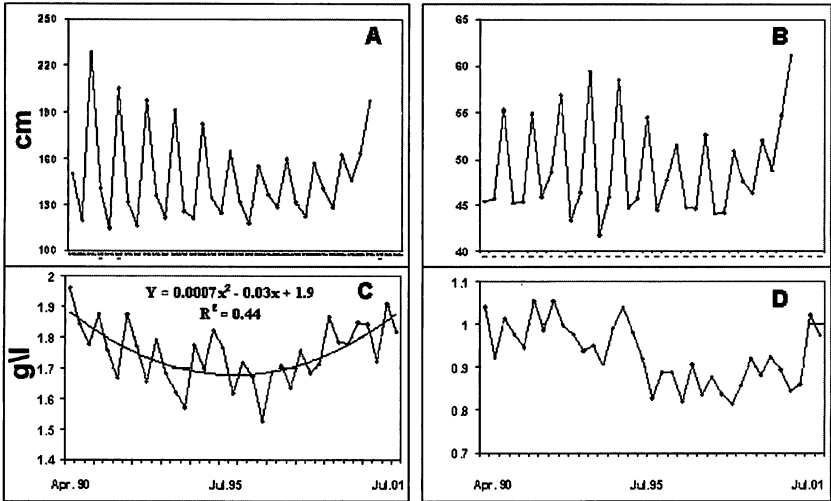


Fig. 3. Temporal changes in (A) groundwater table depth and (B) standard deviation, (C) groundwater salinity and (D) standard deviation.

Average groundwater salinity was 1.77 g/L, but with a wide range from 0.3 to 24 g/L (Table 1). Groundwater salinity was higher in April than in July and October. Such high salinity in the early growing season may have been caused by the 'flushing' effect of solutes from soils through irrigation. The leaching of soil salts generally occurs from mid-February till the end of March before planting. The solute content in river water and groundwater is generally found to be high following the first significant rainfall after a dry spell (Anderson and Burt, 1978). During an irrigation-free period, the amount of solutes in the soils increases due to chemical weathering and salt accumulation via capillary rise. The stored solutes then are easily released into the groundwater during the onset of irrigation. Subsequent irrigation continuously reduces the amount of salts stored in the soil.

The temporal changes in groundwater salinity also corresponded well with the water consumption patterns observed in Khorezm (Fig. 3C, 3D). The average groundwater salinity showed a decreasing pattern until 1995, after which salinity started to increase again (Fig. 3C). Since groundwater salinity in Khorezm is largely derived from salts and chemicals released from soils through leaching (Jabbarov, 1990, Nurmanov, 1966), the decrease of salinity before 1995 might well be explained by the reduction in irrigation activities (Phase II, Fig. 2). Since 1995, however, there has been a clear increase in the average salinity with less variance. This period again coincides with the increased use of irrigation water (Phase III, Fig. 2).

There was a clear difference in the linear increase in the groundwater table and the polynomial groundwater salinity changes during the time period observed (compare Fig. 3A, 3C). We cannot confidently explain such discrepancy at this stage, but we hypothesize that the changes in land management practices might explain the difference. The reduction in agricultural activities in the early 1990s is associated with reduced applications of agrochemicals (Dukhovny et al., 2001). Furthermore, there has been a continuous decrease in financial investments into the maintenance of the irrigation-drainage infrastructure, which may have added to the unfavorable water-salt balance in the late 1990s. Further investigation will be necessary to interpret the temporal dynamics between groundwater depth and salinity.

Groundwater Salinity Spatial Dynamics

In the comparison of the depth of the groundwater level and salinity, the spatial correlation was low. While the spatial distribution of groundwater salinity showed clear regional variation patterns, the spatial distribution of groundwater depth was strongly influenced by local landscape characteristics, such as distance from irrigation, topography, and stratigraphic characteristics of parent materials (Ibrakhimov, 1993). More detailed investigation of the groundwater depth will be

reported elsewhere. In the remaining sections, only groundwater salinity will be considered.

In a semivariogram for the total and monthly averages of groundwater salinity, high nugget variance indicates high small-scale variation among adjacent monitoring wells (Table 2). This is an indication that there was strong short-range heterogeneity of various environmental factors (Isaaks and Srivastava, 1989). The omnidirectional semivariogram (not shown here) revealed a clear directional anisotropy in a northwestern direction, which is clearly shown in the interpolated maps (Fig. 4). In general, salinity in northwest Khorezm was higher than that in the southeast areas, which indicates a gradual salinity increase along the Amu-Darya towards the Sarikamish Depression, which serves as a receiver of the drainage disposals.

Table 2. Semivariogram analysis for average and monthly average of groundwater salinity.

Month	Model	Range (m)	Nugget	Sill	Objective
April	Spherical	21585.86	0.030	0.081	0.0001
July	Spherical	19893.76	0.027	0.075	0.0002
October	Spherical	20762.15	0.029	0.087	0.0002
Total groundwater	Spherical	20853.44	0.028	0.073	0.0002

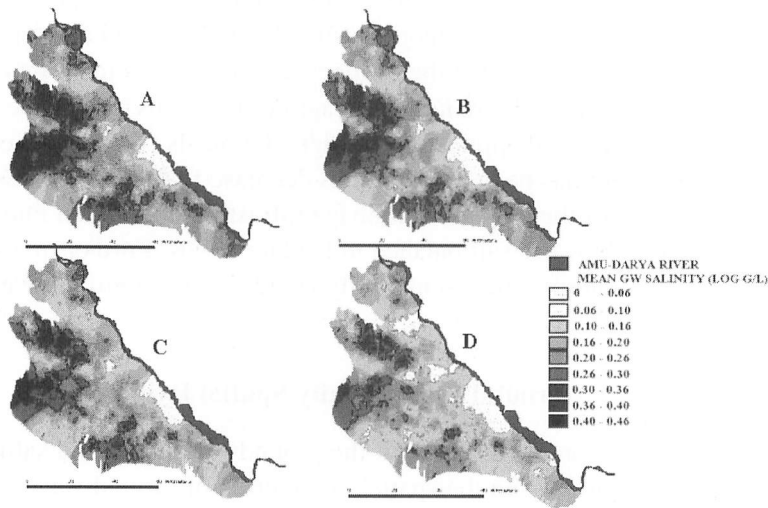


Fig. 4. The spatial distribution of groundwater salinity in Khorezm during 1999-2000. (A) average groundwater salinity, (B) average groundwater salinity in April, (C) same in July, (D) same in October.

Average groundwater salinity is presented in relation to factors, such as the distribution of the main irrigation canals and the soil parent materials (Fig. 5). A visual comparison shows a close spatial association of groundwater salinity with the distance from the river along the irrigation channel. The greatest directional increase in groundwater salinity is strongly associated with the main irrigation channels (Fig. 6). There was a highly scattered but clearly increasing groundwater salinity with increasing distance from the inlet of four main canals. Salt content in irrigation water may increase with the increase of travel time along the main canals.

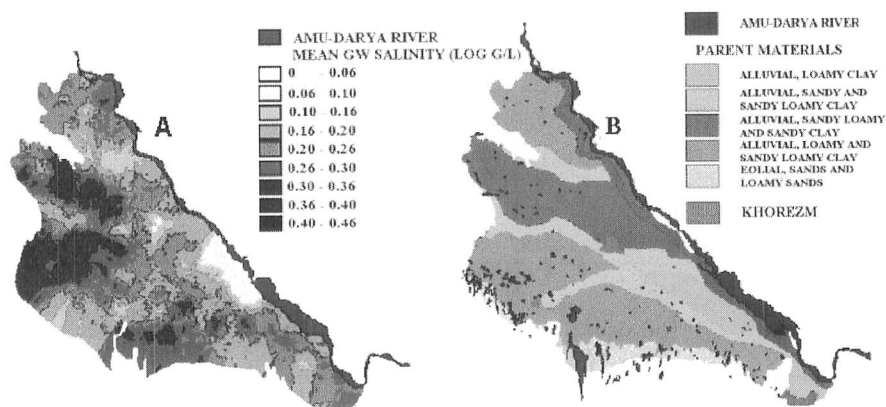


Fig. 5. The comparison of (A) average groundwater salinity and (B) spatial distribution of parent materials and main irrigation canals.

In addition, a clear spatial association between parent materials and groundwater salinity was apparent (Fig. 5). Among the nine lithological and topographical zones, the average groundwater salinity from five zones was compared using a Bonferroni test (Table 3). Salinity was highest in the zone of eolian sands and lowest in the loamy clay zone near the river. In general, the coarser parent materials (loamy and loamic loamy sands) showed higher groundwater salinity than finer (clay or loamy clay) parent materials. Caution is necessary when interpreting the causal relationship between the parent materials and groundwater salinity, since a strong multi-collinearity exists between the different parent materials and the distance from the river. However, the high leaching potential of coarser-textured material may partly contribute to high groundwater salinity (Hillel, 2000).

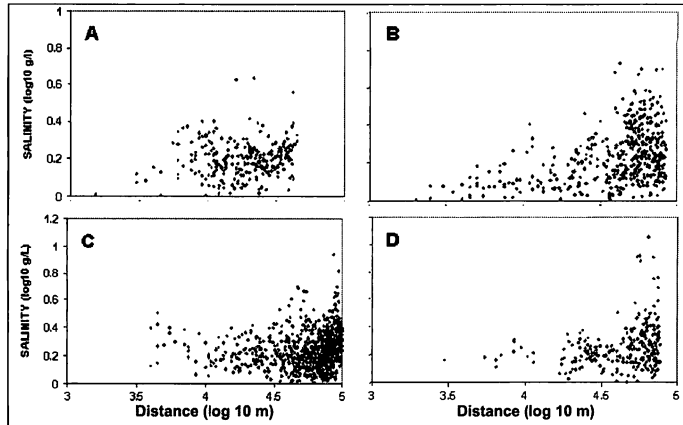


Fig. 6. The relationship between groundwater salinity and distance from the river along the main irrigation canals.

Table 3. Multiple comparisons of the means of groundwater salinity among different parent materials.

Parent material ¹ (I)	Parent material ¹ (J)	Mean Difference (I-J)	Significance ²	95% Confidence Interval Boundary	
				Lower	Upper
Alluvial, loamy clay ¹	ASL1	-0.002	1.000	-0.040	0.035
	ASL2	-0.050	0.002	-0.087	-0.012
	AL	-0.051	0.000	-0.085	-0.016
	EKS	-0.085	0.001	-0.145	-0.023
Alluvial, sandy and sandy loamy clay ²	ALC	0.002	1.000	-0.035	0.040
	ASL2	-0.047	0.000	-0.074	-0.021
	AL	-0.048	0.000	-0.071	-0.026
	EKS	-0.083	0.000	-0.140	-0.026
Alluvial, sandy loamy and sandy clay ³	ALC	0.050	0.002	0.012	0.087
	ASL1	0.047	0.000	0.021	0.074
	AL	-0.001	1.000	-0.023	0.022
	EKS	-0.036	0.768	-0.093	0.021
Alluvial, loamy and sandy loamy clay ⁴	ALC	0.051	0.000	0.016	0.085
	ASL1	0.048	0.000	0.026	0.071
	ASL2	0.001	1.000	-0.022	0.023
	EKS	-0.035	0.754	-0.090	0.020
Eolian, sands and loamy sands ⁵	ALC	0.085	0.001	0.023	0.148
	ASL1	0.083	0.000	0.026	0.140
	ASL2	0.036	0.768	-0.021	0.093
	AL	0.035	0.754	-0.020	0.090

¹ ALC = Alluvial plain interfluvial lowlands, loamy clay; ASL1 = Alluvial plain lowlands, sandy loamy and sandy clays; ASL2 = Alluvial plain lowlands, sandy loamy and sandy clays; AL = Alluvial plain lowlands, loamy and sandy loamy clays; EKS = Eolic knobby underflowed plains, sands and loamy sands

² The mean difference is significant at the 0.05% level.

Ground Water Salinity Changes

Detection of groundwater salinity changes is an essential step to identify the causal relationships of any directional changes within the study region. Many ecological and environmental studies have proven that accelerated changes often occur in some localized areas ("hot spots"), while the majority of land surfaces showed gradual transitions or evolution from one state to another. Identification of such "hot spots" may greatly enhance our ability to identify significant processes underlying groundwater salinity dynamics and allow more site-specific and targeted ecological and policy interventions.

For spatio-temporal environmental data, simple map comparison is often of limited use due to inherent seasonality of environmental variables. The seasonality of groundwater salinity is too pronounced to confidently separate a long-term temporal trend, which may have been caused by irrigation efficiency, salinity of applied water, and drainage conditions. A simple multivariate statistical approach was developed to detect general long-term trends of groundwater salinity (Park et al., 2003).

In this approach, the total variance in spatio-temporal environmental data consists of three variance components:

$$\partial_t^2 = \partial_d^2 + \partial_s^2 + \epsilon$$

where ∂_d^2 is caused by any directional or long-term trend, ∂_s^2 is to seasonal and cyclic changes, and ϵ is the remainder or error term, which includes noise of data caused by measurements and instrumentation. The error associated with measurement is difficult to separate from that in spatio-temporal data sets, and should be considered as a random error. The variance component caused by seasonal variations is the result of the time of irrigation, quality of incoming water, and possible weathering rates. If we separate the seasonality and error components from the total variance of the groundwater salinity, the remainder should yield the long-term temporal changes.

In order to separate the variance component caused by the seasonal trend and the random error components, it is assumed that the variance of the groundwater salinity is linearly correlated with its mean. From the geochemical point of view, this implies that a higher concentration of solutes in the groundwater shows higher seasonal variations over a certain time period. Park and Vlek (2003) studied various spatio-temporal data and conclude that many of them indicate a power relationship between the mean and total variance. When they performed a logarithmic transformation for both, the relationship became linear.

Clear linear relationship between the mean and the variance of the groundwater salinity in Khorezm, as shown in the scatter-plot (Fig. 7) supports their conclusion. The variance was a linear function of the mean of the groundwater salinity with a high coefficient of determination ($\sigma = 1.22z - 0.52$, $R^2 = 0.52$). While most points are scattered along the regression line, some significantly deviate both in positive and negative directions. Those areas that show significant deviation from the regression line reflect significant, possibly human-induced, groundwater salinity changes, which were caused by other than seasonal land management and measurement error. The variance components caused by seasonality and errors were removed from the total variance using a residual analysis.

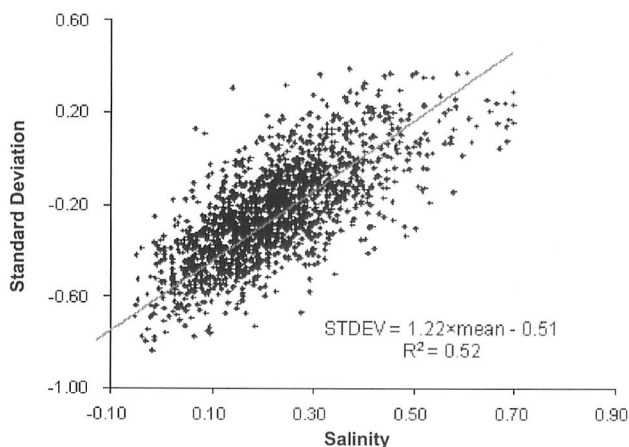


Fig. 7. The relationship between the mean and the standard deviation of groundwater salinity in Khorezm.

The residuals, presented on a standard deviation scale (Fig. 8), indicate the relative intensity of groundwater salinity changes (salinity change index) over the last 10 years. The higher positive salinity change index indicates stronger temporal increasing (or decreasing) trends in groundwater salinity, while a negative salinity change index indicates a stable temporal variance. Some examples (Fig. 8) are shown the temporal changes in groundwater salinity for three selected areas. The first two areas with a high salinity change index show a clear increase in groundwater salinity over the time period observed (Fig. 8A, 8B). However, the areas showing a lower salinity change index are mostly characterized by stable temporal salinity patterns (see Fig. 8C).

The spatial distribution of the intensity of groundwater salinity changes indicates that change is not spatially random. Instead, it is spatially organized and there are spatial domains where underlying processes and salinity dynamics may

differ from those in other areas. The two examples given in Figure 8A and 8B are characterised as the domains with the most rapid increase in groundwater salinity during the last decade. Detailed investigation of the land management and irrigation efficiency is ongoing, but it is already interesting to note that these "hot spots" are in the vicinity of highly saline groundwater zones (compare Fig. 5A, Fig. 8). This is a clear indication that the highly saline areas are expanding towards the River from the already saline areas at the end of the main irrigation canals. A similar relationship is also apparent in the areas marked D and E in Figure 8.

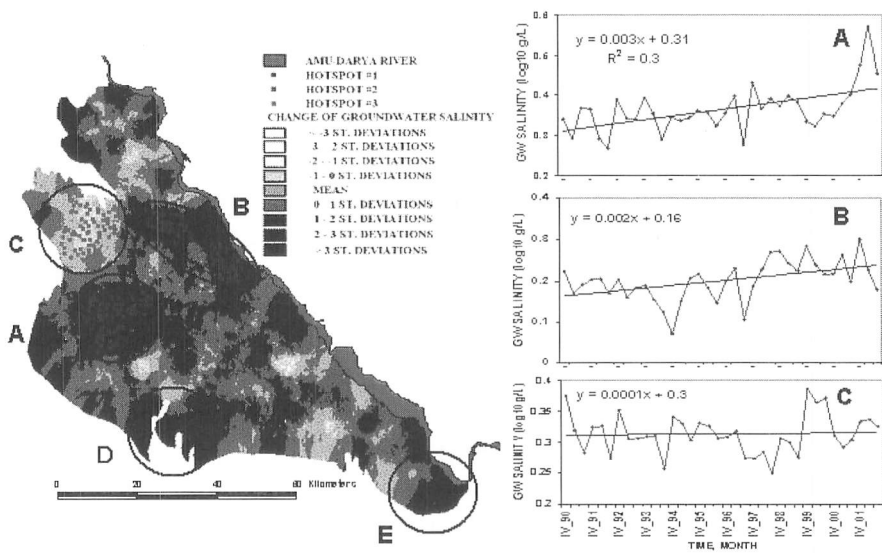


Fig. 8. The residual of soil salinity from the linear relationship between mean and standard deviation of groundwater salinity, and the changes of groundwater salinity at three specific areas (A, B, C).

CONCLUSIONS

Considering the strong dependence of the whole lower Amu-Darya region on the quality and quantity of river water, ecologically sustainable water management is the most critical issue. The comparison of water discharge, measured at two hydrological stations along the Amu-Darya River clearly suggests the reason for the Aral Sea crisis as being related to the socio-economic situation driving the water consumption in the Basin. The progressive increase in water consumption from 1995 onward, whose time period is concordant with the introduction of economic reforms and agricultural diversification, indicates that a further reduction of water leaving Khorezm is inevitable in the near future if current land management practices continue.

Considering the fact that the desiccation of the Aral Sea is irrigation-driven and the water deficiency has been the direct cause of the *economic and ecological disaster in the further downstream* areas (e.g., Karakalpakstan), an increase in water-use efficiency in Khorezm is essential for the economic sustainability of the Aral Sea Basin. Since Uzbekistan is undergoing rapid socio-economic changes in its transition from the centrally planned Soviet system to a free-market economy, a more ecology-driven, sustainable land-use policy is the most urgent.

This detailed investigation of the spatio-temporal dynamics of groundwater salinity provides a clear policy direction for this issue. A change detection method applied to the groundwater salinity revealed that during the last decade highly saline groundwater zones were expanding from already saline areas. It is of paramount importance to be fully aware of the spatial heterogeneity or variability of processes that might be taking place in different areas.

In scientific communities, it is widely accepted that certain technological and policy interventions disseminated at a national level may not be appropriate at the local level. One of the fundamental stumbling blocks for more effective policy intervention is the spatial heterogeneity of socio-economic and biophysical conditions at the local level. Over the whole Khorezm region, there is a large variability of soil types, irrigation systems, and parent materials. Locally, farmers may also respond differently to policy changes, due to their cultural, natural and socio-economic situation.

Furthermore, such spatial heterogeneity of natural and socio-economic factors often leads to localized accelerated changes over the landscape ('hot spots'). Ignoring such temporal extreme events and "hot spots" may lead to false conclusions regarding stability and causal relationships of the system. The strong spatial heterogeneity of groundwater salinity variation observed in Khorezm calls for a more site-specific approach to water use and management in order to preserve local environmental conditions.

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Improved On-Farm Water Management Strategies in Central Asia

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ABSTRACT

This paper presents summary results of testing strategies for better on-farm management in the conditions of large irrigated areas of Central Asia. The strategies comprise testing of improved alternate furrow irrigation for field crop irrigation (cotton) and an advanced drip system on vineyard orchards combined with intercropping practice, which aimed to optimize resources use and maximize economic returns. The research was conducted

on heavy loamy soil in Arys Turkestan district of Kazakhstan during 1999-2002 for field crop irrigation using alternate furrow irrigation and low pressurized drip irrigation on a sloping area of Boykozon, Uzbekistan, during the 2001-2002 season. Both experimental sites are agroecologically representative of large irrigated areas of the region.

The objective was to assess the influence of improved alternate furrow irrigation on efficiency of water use, evapotranspiration, soil water and salt balance, and yield of raw cotton. Along with improving of irrigation practice, phosphogypsum was tested to improve soil properties and increase water productivity in conditions with magnesium dominating the soil absorption complex.

Cutback alternate furrow irrigation was highly efficient on heavy loamy soil and did not require additional investment. This technology improves conditions for conducting irrigation, reduces irrigation rate by about 30%, and reduces pressure on a drainage system by about 40%. The application of 4.5 t/ha of phosphogypsum, an industrial byproduct from the P fertilizer industry, provided higher short-term return.

The drip system was tested for irrigation of young vineyards and intercropped vegetables in a 1-ha area. The research data showed that growing intercropped vegetables between young vineyards permitted full recovery of expenses for capital cost installation of the drip system during the first two years. The study indicated that free marketing of agricultural products becomes very important for wide dissemination of advanced irrigation technologies.

INTRODUCTION

On-farm water management is key to the development of a new water strategy in Central Asia. Difficulties, associated with a decline of economic and living standards, followed by an increase in the number of independent water users, due to the fragmentation of large collective farms (1-10 Kha) into small farms (1-50 ha), requires reconsideration of soil and water management. The most comprehensive approach to the problem entails support of Water Users, Associations that are functioning in almost all countries of the region. These associations face many constraints, especially low financial capabilities of farmers. Charges for water use appear to be a precondition for wide dissemination of water-saving technologies. However, only in some cases are advanced technologies reasonable for small farms having net profit below 300 USD/ha. Thus, there was need for research to develop, adopt and disseminate appropriate water-saving irrigation technologies for small farms of Central Asia.

Furrow irrigation is a main method of irrigation of arable crops in Central Asia. Furrow irrigation advantages and disadvantages were examined in detail by Lactaev (1978). Simplicity and low energy consumption, along with high water use, are typical patterns of furrow irrigation. However, a gradual increase of water deficit in the region and the orientation of the agriculture to market economy requires improving of water-use efficiency. In the water-deficit areas of the region, alternate furrow irrigation can substantially increase of water productivity and in turn help agricultural sustainability and improve environmental quality. Alternate furrow irrigation promotes better thermal supply of crops, facilitates both of irrigation and soil cultivation, and reduces unproductive water losses.

The objective of this research was to assess the influence of improved alternate furrow irrigation on efficiency of water use, evapotranspiration, water and salt balance and yield of raw cotton. Discrete and cutback alternate furrow irrigation methods were tested during 1999-2002 at the experimental site in the Arys Turkestan district of Kazakhstan.

Along with the water deficit in the region, another problem is a reduction of soil fertility due to reasons such as low application rates of fertilizers, monoculture, and an increase of soil salinity. The use of some local industry byproducts, otherwise considered wastes, can improve soil properties. One of them is phosphogypsum, containing calcium and phosphorus. At an area having magnesium salinity, calcium contained in phosphogypsum displaces magnesium in soil absorption complex and promotes of its leaching from the soil profile. Using phosphogypsum also enriches the soil with available phosphate. Phosphogypsum was tested at the part of the experimental site having magnesium salinity.

Advanced irrigation technologies are another opportunity to improve water productivity in the region. There are pre-conditions for wide application of drip and sprinkler irrigation technologies. Acceptability and availability of a technology at affordable cost are some of the main pre-conditions. Deterrents are low economic incentives to water saving and lack of free marketing of agricultural production in most countries of the region. Increased water deficit in the region and improved interstate economic cooperation will promote adoption of advanced technologies for irrigation of high value cash crops, such as vegetables, melons and fruit trees. Low pressurized drip system was tested during 2001-2002 in Boikozon, Uzbekistan, for irrigation of young vineyards and intercropped vegetables at area 1.0 ha.

Terminology

For assessment of the efficiency of the technologies, the following indexes were used: water-use efficiency (WUE); efficient water use (EWU); and recovery efficiency (REW). Water-use efficiency (physiological efficiency) is the biomass

production per unit cropped area for a unit of water evaporated and transpired

$$WUE = Y / ET,$$

Where, Y is yield of crop, kg/ha; ET is evapotranspiration, m³/ha.

Efficient water use or yield efficiency is the ratio of biomass to all available water.

$$EWU = Y / Wa,$$

Where, Wa is all available for crops water, m³/ha. The EWU index indicates technical efficiency of the water use technology.

Recovery efficiency is the ratio of water used (ET or T) to all available water.

$$REW = ET \text{ (or } T) / Wa.$$

All available water includes irrigation water, precipitation, reduction of soil moisture during vegetation season, and upward flow. The upward flow originates from deep losses from irrigated areas and canals. Exclusion the upward flow from the amount of available water brings an overestimation of efficiency of water use in terms of EWU and REW.

METHODS

Study Areas

The Arys Turkestan site, for improved alternate furrow irrigation, is located in southern Kazakhstan, in the northern cotton-growing area, and has a flat relief occupying an area of 50 ha. Annual precipitation ranges from 50 to 250 mm, with 90% occurring during the October through May period. Soil is meadow Sierozem, heavy loam, mainly non-saline, with organic matter content in topsoil about 1%. Soil bulk density was 1.47 g/cm³ at 0-50 cm of soil layer. There were some moderately saline spots at the experimental site. At the part of the area magnesium was dominating in the soil absorption complex. The main crop in the district was cotton. Irrigation water shortage and low water-use efficiency were the main challenges in this area.

The experimental site on a low pressurized drip system is located in Boikozon, Tashkent province, Uzbekistan, at 525 m above the sea level, with coordinates 41.24° of the northern latitude and 69.78° of the eastern longitude. The area is predominantly hilly. Climate is extremely continental, and average annual temperature is 14.3°C. During the October through May period, precipitation ranges

from 290 to 600 mm, i.e., 90% of annual rate. Soil is typical sierozem, light clay with organic matter content from 0.35 to 0.88% in topsoil. Soil bulk density is 1.42 g/cm³ at 1.0 m of soil layer. Water permeability of soil is 0.2-0.6 mm/min. High surface runoff and soil erosion are the main challenges of the existing irrigation practice.

Installation and Sampling

To improve water-use efficiency on a heavy loam soil of the Arys Turkestan site, improved alternate furrow irrigation technique (*cutback* and *discrete furrow*) was tested in comparison with *traditional furrow* and *alternate furrow* irrigation.

The following treatments were studied:

- a) *Control*. Alternate furrow irrigation with irrigation jet discharge rates adjusted to those practised by neighboring farmers.
- b) *Cutback*. Alternate furrow irrigation (water discharge was close to soil absorbency).
- c) *Discrete*. Alternate furrow irrigation.

Performance of existing furrow irrigation was monitored on selected farms of Arys Turkestan district with similar soil conditions. Lysimeter studies of transpiration of cotton and physical evaporation were conducted using alternate furrow irrigation and having groundwater at depths of 1.0, 1.5 and 2.0 m below the soil surface.

On-farm irrigation scheduling depended considerably on regularity of water supply. The actual irrigation scheduling varied in four years: 1-3-0 (before flowering, during flowering, during ripening of cotton) in 1999, 0-2-0 in 2000, 1-2-1 in 2001, and 1-3-0 in 2002. Accordingly, threshold of pre-irrigation soil moisture amounted to: 65-70-60% of field moisture capacity (FMC) in 1999; 60-60-55% in 2000; 60-65-55% in 2001, and 60-65-60% in 2002. The irrigation was conducted on 420-m long, 90-cm wide and 15-cm deep furrows. The experience had two replications; an area of each irrigated plot was 1.0-1.2 ha. The farming practice was according to the standard for this zone.

Efficiency of phosphogypsum was tested at the part of the site with the soil having properties similar to *takyr* and dominating of magnesium in the content of absorbed cations. Application rates 4.5 and 8.0 t/ha of the phosphogypsum were studied. The smaller rate was applied on 2.0 ha area and the second on 1.0 ha area.

The low-pressurized drip system was studied on steep slopes for irrigation of young vineyards with annual crops, grown in the row spacing at Boikozon site, Uzbekistan. The drip irrigation was tested alongside with traditional furrow irriga-

tion. The system was installed on a 1.0 ha area. Tensiometers were installed at depth of 30, 50, 70 and 100 cm to monitor soil moisture. Pre-irrigation soil moisture for grapevines, watermelons, peppers and tomatoes was 80-85% of field moisture capacity, for cucumbers 70-75%.

RESULTS

Improved Alternate Furrow Irrigation

Irrigation areas located downstream the river in remote area from water sources are being often exposed to water shortage. In this case, limited water resources might lead to considerable cutback of crop production. To address this issue, alternate (cutback and discrete) furrow irrigation was tested at the Arys Turkestan site, Kazakhstan.

Soil Moisture Content

The survey conducted in selected farms of the Arys-Turkestan district revealed that technological losses during furrow irrigation could be broken down as follows: 55-60% of applied water was accumulated in the soil, 20-22% was lost for deep percolation; 7-8% for evaporation during irrigation, and 10-15% for surface runoff. The significant amount of the water losses reduced a reliability of the drainage system and the water supply level of the agricultural crops at the area.

At the experimental site, structure of expenditures of irrigation water was presented in the following way (Fig. 1). Having alternate furrow irrigation, a share of water accumulated in the soil increased by 12-20%, a share of losses for deep percolation reduced by 10-25%, a share of losses for evaporation during irrigation reduced by 33%, respectively, during dry and wet years compared to traditional furrow irrigation.

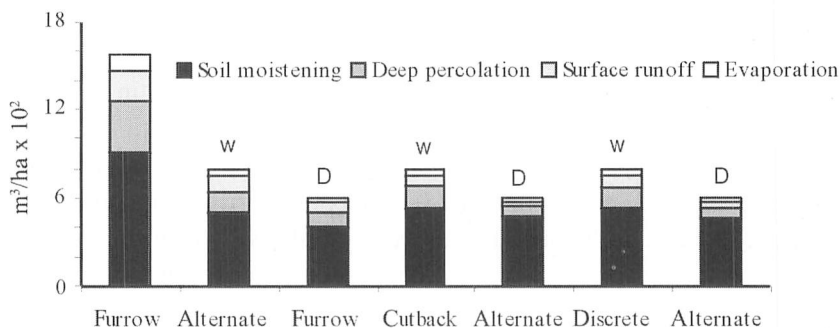


Fig. 1. Irrigation flow pathways under alternate furrow irrigation in wet (W) and dry (D) year.

Thus, when alternate furrow irrigation was applied, crop water use was increased, because of reduced physical evaporation from the dry furrows. Having cutback alternate furrow irrigation, a jet discharge into furrows was regulated to minimize a surface runoff from irrigated furrows. From the beginning to the end of the irrigation, jet into furrows was reduced from 0.7-1.0 L/s to 0.3-0.5 L/s. At this option, a share of water accumulated in the soil increased by 21-33%, a share of losses for deep percolation reduced by 18-42%, a share of losses for evaporation during irrigation reduced by 33%, a share of surface runoff reduced by 37-50%, respectively, compared to traditional furrow irrigation. This indicates that if cutback alternate furrow irrigation was applied, deep percolation losses and surface runoff could be reduced significantly.

Having discrete alternate furrow irrigation, water was delivered to the system periodically by reducing water diversion and regulating a jet in the furrows. Depending on the irrigation rates, a share of water stored in the soil profile increased by 8-20%, a share of losses for deep percolation reduced by 23-50%, a share of losses for evaporation during irrigation reduced by 27%, a share of losses for surface runoff reduced by 23-30%, respectively compared to traditional furrow irrigation. This indicates, when discrete furrow irrigation was applied, deep percolation losses could be managed well.

Maximum soil moisture was recorded at the irrigation rate of 600 m³/ha water losses have increased with higher irrigation rate. At the irrigation rate 600 m³/ha water losses reduced down to 20% from water applied.

Evapotranspiration

The research data indicate that evapotranspiration is a function of the crops' growth stage, irrigation technology, dates of inter-row tillage, etc. Between irrigation and day of inter-row tillage, ET varied in range of 13-15 mm/day with furrow irrigation and 9-11 mm/day with alternate furrow irrigation. After inter-row tillage, ET went down to 7-9 mm/day for the furrow irrigation and 5-6 mm/day for the alternate furrow irrigation, respectively.

Physical evaporation from soil under furrow irrigation varied in range of 25-40% of ET. In the lysimeter studies using alternate furrow irrigation, the physical evaporation was much lower: 20%, 18% and 12%, respectively, having the groundwater level at 1.0 m, 1.5 m and 2.0 m deep. Pre-irrigation soil moisture was 80% for groundwater level at 1.0 m and 65% of FMC for groundwater level about 1.5-2.0 m. Using alternate furrow irrigation at the experimental site, the losses for physical evaporation from the soil were reduced twice comparing with irrigation by furrows, i.e., around 15% of ET, whereas transpiration increased from 71 to 85%.

The research data indicated that cotton was easily adapted to water shortage in the first stages of the growth. A delay of the first irrigation until full budding stage increased penetration rate of cotton roots in the deep horizons. Water deficit later on, especially in the end of July has resulted in wilting of cotton, a loss of bolls and reduction of the yield. The effect of cutback alternate furrow irrigation on cotton yield and water use efficiency is shown in Table 1.

Table 1. Alternate furrow irrigation vs. cotton yield and water-use efficiency¹.

<u>Parameter</u>	<u>Alternate furrow irrigation</u>			
	<u>Furrow</u>	<u>Control</u>	<u>Cutback</u>	<u>Discrete</u>
Raw cotton yield (t ha ⁻¹)	2.35	2.57	2.60	2.55
Availabe water resources(m ³ ha ⁻¹)	8550	6717	6520	6400
Evapotranspiration (m ³ ha ⁻¹)	6650	5800	5800	5800
Efficient Water Use (kg m ³)	0.27	0.395	0.42	0.39
Water Use Efficiency (kg m ³)	0.35	0.435	0.44	0.43
Recovery Efficiency	0.78	0.89	0.91	0.91

¹ Data from 1999-2002

The data revealed that yield of raw cotton increased using cutback and discrete irrigation by 10 and 8%, respectively, compared to furrow irrigation. Improved alternate furrow irrigation reduced instability of cotton yield by optimal irrigation timing compared to the plot where the farmer irrigated the cotton based on his experience. Having improved alternate furrow irrigation, EWU index increased by 25-85% and WUE index increased by 8-57% compared to furrow irrigation, respectively. Reduction of physical evaporation from soil surface contributed to an increase of WUE. Increased EWU and REW compared to control was achieved through reduction of surface runoff in average by 34 and 38%, and deep percolation by 11% and 17%, respectively, using cutback and discrete alternate furrow irrigation. Thus, when alternate furrow irrigation was applied, water use efficiency was increased, because of reduced surface runoff, deep percolation, and physical evaporation from the dry furrows.

The REW index increased by 15, 17 and 17% compared to furrow irrigation, respectively, having control, cutback and discrete irrigation. However, average differences in REW for 1999-2002 between alternate (control), and cutback and discrete irrigation treatments were not significant. High values of REW can be explained by significant upward flow, thus this index accounts only losses of irrigation water for surface runoff.

Assessment of soil salt balance showed that during cotton vegetation some positive salt balance was registered. In average for 1999-2002, a total salt amount in 1-m soil layer from spring to fall had increased by 4.65, 1.91 and 0.36 t ha⁻¹ under control, cutback and discrete irrigation, respectively. In 1-2 m of soil layer, the salt content increased by 0.72 t ha⁻¹, 1.25 t ha⁻¹, respectively, for cutback and discrete alternate furrow irrigations. Under control treatment a negative salt balance was obtained in the 1-2 m of soil layer. These data proved that increased salinity under traditional practice compared to cutback or discrete irrigation can be explained by high initial level. Leaching promoted a negative salt balance in the soil.

Phosphogypsum

The high content of magnesium in relation to absorbed cations may cause retardation of cotton development. Phosphogypsum was tested at part of the area having magnesium salinity to improve soil properties. It was incorporated in the soil by plowing in February 2001. A good rainfall during March and April contributed to dissolution of phosphogypsum and its movement to lower soil horizons. Spring pre-sowing irrigation on May 2-6 with rate 1.0-1.5 1000 m³ ha⁻¹ has leached further the exchangeable Mg that was displaced from absorption complex of the soil, whereupon the cutback alternate irrigation was used at the studied area.

Using phosphogypsum with rate 4.5 t ha⁻¹ has increased the content of exchangeable Ca by 0.96 t ha⁻¹, exchangeable Mg content reduced by 0.64 t ha⁻¹, and content of Na did not change. Using phosphogypsum with rate 8.0 t/ha has increased content of exchangeable Ca by 1.13 t ha⁻¹, exchangeable Mg content reduced by 0.91 t ha⁻¹ and content of Na did not change. Using phosphogypsum with rate 4.5 t ha⁻¹ promoted leaching of 142 kg of Mg and accumulation of 213 kg of Ca per ton of applied phosphogypsum. Using 8.0 t ha⁻¹ ensured leaching of 228 kg of Mg and accumulation of 283 kg of Ca per ton of the applied phosphogypsum. The ratio of exchangeable Ca/ exchangeable Mg significantly improved.

Moreover, using phosphogypsum increased content of exchangeable P in the topsoil. With 4.5 and 8.0 t ha⁻¹ of phosphogypsum, a content of mobile form of P increased by 38 (24%) and 77 kg ha⁻¹ (44%) in the soil layer 0-40cm, respectively. Changes of content of mobile N were not significant. The content of K₂O in 0-20 cm topsoil increased from 6 to 8% using rate 4.5 and 8.0 t ha⁻¹, respectively. Improvement of soil fertility as affected by applying of phosphogypsum was reflected by increase of cotton yield. The yield of cotton at the site was 3.0 t ha⁻¹ applying phosphogypsum with rate 8.0 t ha⁻¹, 2.7 t ha⁻¹ with rate 4.5 t ha⁻¹ and 1.4 t ha⁻¹ without phosphogypsum. Before using phosphogypsum in 2000 at the site with magnesium salinity, the yield of cotton was only 0.8-1.1 t ha⁻¹. Using

phosphogypsum promoted receiving of additional 289 and 200 kg of raw cotton per ton of applied phosphogypsum respectively for rates 4.5 and 8.0 t ha⁻¹. Therefore, the rate 4.5 t ha⁻¹ of phosphogypsum provided higher short-term effect. Using rate 8.0 t ha⁻¹ provided higher increase of Ca in the soil absorbing complex and increase of available forms of phosphates in the soil for multiple growing seasons.

Economic Efficiency

Economic assessment of the irrigation at the experimental site indicated that in water shortage conditions water has become one of the significant agro-economic factors for production of raw cotton. Expenses for irrigation, including making water distribution and irrigation furrows, and delivering the water amounted 34-38 US\$/ha in 2000, 46-60 US\$/ha in 2001, 43-51 US\$/ha in 2002. In 2001, because of water shortage during summer, water was provided from vertical wells and this considerable increased the cost of irrigation.

A share of water in the cost of the inputs(including seeds, fertilizers, water and pesticides) amounted from 18-26% in 2000, 52-62% in 2001 and 29-33% in 2002. In the whole, expenses for water and for conducting the irrigations totaled from 41-44 US\$/ha in 2000, 96-101 US\$/ha in 2001 and 62-64 US\$/ha in 2002. In other words, the share of expenses for water delivery and irrigation amounted to 18-23% from prime costs in 2000, 29-35% in 2001, 21-27% in 2002.

The data showed that a share of manual labor in the cost of cotton production was in range of 34-35% for low fertile soil and 40-43% for moderately fertile soil. Improved alternate furrow irrigation increased net profit of the farming by 61.4 US\$/ha and 41.4 US\$/ha on average using cutback and discrete alternate furrow irrigation, respectively.

At the experimental site with often irrigation water shortage, efficiency of irrigation technology could be identified through net profit of farming per m³ of applied water. A net profit using traditional furrow irrigation was 0.10 US\$/m³, using the alternate furrow irrigation 0.33 US\$/ha, the cutback alternate furrow irrigation up to 0.41 US\$/m³, and having the discrete furrow irrigation 0.38 US\$/ha. The cutback alternate furrow irrigation provided highest return per m³ of water.

Expenses for purchasing, transportation (350 km) and applying 4-8 t ha⁻¹ of phosphogypsum varied in range of 135-230 US\$/ha. Using the phosphogypsum increased the yield of raw cotton by 1.3-1.6 t ha⁻¹. Cost of the additional yield of raw cotton amounted to 240-296 US\$/ha. The net profit reached to 51.4 US\$/ha using rate 4.5 t ha⁻¹. Using the rate 8.0 t ha⁻¹ of phosphogypsum required more than one year for the cost recovery.

Self-Pressurized Drip Irrigation Technology for Steep Slopes

Furrow irrigation along the slopes prevalent in foothill areas of Central Asia causes significant surface runoff and soil erosion. One of the options to improve water-use efficiency under these conditions could be drip irrigation. The main constraint for wide dissemination of drip irrigation is the high investment cost. Fortunately, on sloping area, difference of altitudes allows reduce cost for installation and maintenance of the system.

A farm irrigation system in Boikozon is made of reinforced concrete parabolic flumes, constructed along the hill heads. Difference in altitudes between top and bottom of the hills is 20-40 m. This allowed for design a drip system without pumps. Working pressure of the system was received due to 18 m difference of altitudes of water diversion and water distribution head end nodes. Biennial saplings of grapevines were planted on April 2001 by scheme 3.5 x 3.0 m. Intercropped melons and vegetables were irrigated by autonomous line. Water distribution pipelines were placed underground. Irrigation pipelines with drippers were laid out on the soil surface along the grapevines and vegetables. A distance between drippers was 3 m under grapevines and 1 m under intercropped vegetables. Total cost of installation of the system amounted to 2,246 US\$.

Pre-irrigation soil moisture was in range of 80-85% under grapevines, tomato, pepper and melons, and 70-75% under cucumbers. The duration of irrigations of grapevines was 16 hours, of tomatoes, cucumber and watermelons 7 hours, of pepper 10 hours. Discharge of drippers was 2.82 L hr⁻¹ under grapevines, 2.7 L hr⁻¹ under tomatoes, 1.87 L hr⁻¹ under pepper, 2.41 L hr⁻¹ under melons and 2.9 L hr⁻¹ under watermelons. In 2001, 20 irrigations of grapevines were conducted using the drip system at 61 m³ ha⁻¹ rate each, 9 irrigations of tomatoes with rate 197 m³ ha⁻¹ each, 10 irrigations of cucumbers and pepper with rate in range of 184-188 m³ ha⁻¹ each, 6 irrigations of melons and 7 irrigations of watermelons using rate 222 m³ ha⁻¹. From the first year the yield of inter-crops was obtained (Table 2).

Table 2. Efficiency of water use using drip irrigation at Boykozon site (2001-2002).

Parameter	Grapevines	Tomatoes	Cucumbers	Pepper	Watermelons
Yield, t ha ⁻¹	0-0.48	29.9	4.5	13.4	7.84
Total water available, m ³ ha	1226-2470	1988	1843	1850	1335
Evapotranspiration, m ³ ha	1126-2320	1838	1693	1700	1185
Efficient water use, kg m ⁻³	0.19	15.15	2.44	7.25	5.87
Water use efficiency, kg m ⁻³	0.22	16.42	2.66	7.89	6.62
Recovery efficiency	0.94	0.92	0.92	0.92	0.89

Values of water use efficiency indicated that efficiency of water use as affected by irrigation technology (EWU) was close to physiological efficiency (WUE). It was proved also by value of REW that was close to 1. The values of REW indicate losses of irrigation water to lateral subsoil outflow (that was available for the crops in the next row by the slope) and losses of precipitation for surface runoff (totally 8-11%).

Survival rate of grapevines in 2001 amounted to 66%. That is why additional saplings of grapevine were planted at the site in May 2002. Three treatments were studied in 2002: irrigation of grapevines; grapevines and inter row spacing tomatoes; grapevines and inter row spacing pepper.

In 2002, a total of 20 irrigations of grapevines were conducted using drip system at $123 \text{ m}^3 \text{ ha}^{-1}$, 7 irrigations of tomatoes with $314 \text{ m}^3 \text{ ha}^{-1}$, and 7 irrigations of pepper using $260 \text{ m}^3 \text{ ha}^{-1}$. The data obtained proved that 2002 was first yielding year for grapevines, therefore low values of efficiency of water use received. The growth and development of grapevines planted in 2001 was normal, and already during the second year 480 kg ha^{-1} of grapevines was received. Inter-cropped tomato and pepper produced 31 t ha^{-1} and 14 t ha^{-1} of products, respectively. Values of water use efficiency indexes were close to the previous year.

Economic assessment of the developed drip system proved that this technology could be widely adapted by farmers. Using drip technology has allowed to the farmer growing intercropped vegetables and watermelons during first two-three years, while under traditional furrow irrigation this advantage was very limited. The agro-economic input of drip irrigation comprise 19% of total cost was to purchase seeds and fertilizers, 2% for soil tillage, 5% transportation, 12% labor cost, 2% taxes and 60% was depreciation allocation for the system recovery. It means that expenses for the recovery drip system formed more than half of the total expenses.

Economic data from this experiment and applicable and representative economic data from the region reveals that intercropping strategy allowed to compensate expenses for installation of the drip system during first two years. During 2002, total production value of cucumbers amounted to 1,440 US\$, tomatoes 156 US\$, watermelons 273 US\$, melons 86 US\$, peppers 36 US\$ and grapevines 14 US\$. Net profit amounted to 1,683 US\$. Taking into consideration that cost of installation of the drip system was 2,246 US\$ and similar net profit was during 2001, it can be concluded that the capital cost of drip irrigation system was recovered during the two first years.

The study is indicated that improved low-pressurized drip system harmonized irrigation needs of young grapevines and inter-crop vegetables and melons. Actual irrigation rates for drip system with inter-row vegetables and melons were 1.5-2.0 times less comparing with furrow system. The study indicated that free marketing

of agricultural products becomes very important for wide dissemination of advanced irrigation technologies.

SUMMARY

Water has become the most critical resource for middle stream of the Syr-Darya River. The share of agronomic production input has reached to 18-35% from prime cost depending on water availability. The research proved that cutback alternate furrow irrigation was highly efficient at heavy loamy soil and did not require additional investment. This technology improved the environment for conducting irrigations, reduced irrigation rate by 30% and pressure to a drainage system on 40%.

Irrigation water losses for deep percolation and surface runoff were reduced twice. Salinity increase in the topsoil during vegetation season was not significant, having appropriate farming practice and drainage system. Irrigation rates were reduced up to one and half times, because of reduction of physical evaporation up to twice.

Application of phosphogypsum at low fertile soil, with magnesium accumulation in the soil absorption complex increased profits of farmers and improved soil properties. Application of 4.5 t ha⁻¹ of phosphogypsum provided higher short-term return. Using 8.0 t ha⁻¹ required a long-term effect.

Low-pressurized drip system was cost effective at steep slopes for irrigation of young vineyards and intercropped vegetables. The study indicated that improved low pressurized drip system harmonized irrigation needs of young grapevines and inter-crop vegetables and melons. Actual irrigation rates for the drip system with inter-row vegetables and melons were 1.5-2.0 times less comparing with the furrow system. Growing intercropped vegetables between young vineyards permitted fully recover of expenses for installation of the drip system during first two years. The study is indicated that free marketing of agricultural products becomes very important for wide dissemination of advanced irrigation technologies.

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Increasing Water-Use Efficiency in Sloping Areas of Tajikistan and Uzbekistan.

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ABSTRACT

Low water-use efficiency and soil erosion are the main constraints to improved agricultural production in the sloping areas of Tajikistan and Uzbekistan. The soil degradation could be arrested by introducing water-saving and soil conservation technologies such as *strip cropping*, *supplemental irrigation*, *mulching*, and *contour irrigation*. During 2000-2002, these technologies were studied at different agroecological conditions of the region. Strip cropping and mulching was tested in semi-humid zone at Faizabad site,

Tajikistan. The objective of this research was to assess the influence of strip cropping on combating of soil erosion. Using sloping areas for growing of wheat has resulted in increased soil erosion by 50% compared to natural grasses. Supplemental irrigation and different mulches were practised to grow trees on terraces in semi-arid zone at Fakhrabad site, Tajikistan.

Under these conditions, supplemental irrigation and mulching with plant residues increased soil moisture contents and survival rate of the trees during the dry season. Applying furrow irrigation to winter wheat on sloping areas in the semi-arid conditions resulted in soil fertility reduction. At the same time, contour and *joyak* (zigzag furrows) irrigation tested at Boikozon site, Uzbekistan, almost completely controlled soil erosion at the sloping area, increased winter wheat yield by 2.0-3.6 t ha⁻¹ and water use efficiency by 30% comparing to the traditional practice. These three experimental sites are agroecologically representative of large sloping areas of the region.

INTRODUCTION

Sloping land areas are widespread in Tajikistan, Kyrgyzstan, and Uzbekistan, and less so in Kazakhstan and Turkmenistan. These areas have better water supply compared to lowlands. At the same time, the soils are more vulnerable and liable to degradation caused by poor rainfed farming and irrigation practices. Depending on the amount of precipitation, the area is divided into sub-humid and semi-arid zones. Precipitation, exceeding 600 mm in the sub-humid zone, causes significant surface runoff and soil erosion. Water erosion is most prevalent and causes the greatest soil loss; however wind erosion is serious in several areas.

Strip cropping in combination with crop rotation was tested in these conditions to protect soil. In the semi-arid zone, precipitation is in the range of 300-500 mm. Periodic water shortage is the limiting factor for rainfed farming in the zone and requires effective soil moisture maintaining practices such as terracing, narrow strips, mulching, and supplementary water supply. Traditional furrow irrigation in the semi-arid zone is entailed with significant surface runoff and widespread soil erosion. Surface runoff from sloping areas under irrigation reaches 5,000 m³ ha⁻¹ and soil erosion exceeds 5 ton ha⁻¹. The farming system in sloping areas is poorly developed due to low mechanization and lack of fertilizer.

Another constraint is low efficiency of irrigation water use caused by non-uniform soil moisture distribution along the slopes. Testing of contour and *joyak* (zigzag) furrows in the semi-arid zone revealed water saving technologies in these areas could improve water productivity and reduce soil erosion. Advances in water conservation and water-use efficiency can promote reduced erosion and increasing agricultural production at the sloping areas.

METHODOLOGY

The Study Areas

The Faizabad site is located in the rainfed area of Tajikistan's foothill zone, with an altitude of about 1200 m above the sea level. Landscape is mainly hilly and slope gradients vary from 8 to 40%. Climate is acute continental, with high summer temperatures and uneven distribution of precipitation throughout the year. Annual average temperature is 12.1 °C, with lowest temperature occurring in January (0.3 °C) and highest in July (25.5 °C). Annual precipitation is in the range of 750-850 mm, mainly occurring in the winter and spring.

The soil was moderately eroded, brown carbonate, heavy loam, with total contents of nitrogen 0.08-0.21%; CaCO₃, 15-18%; and field capacity, 22%. Originally, brown soils have a 30-35 cm thin layer with organic matter content between 3-5%; however, due to soil erosion, organic matter content in this region is in the range of 1.0-1.6%. Soil bulk density is 1.09 g cm⁻³ in the 0-10 cm layer and 1.41 g cm⁻³ in the 10-40 cm layer.

The Fakhrrabad site is located in Rasulev Farm of Gozimalik district in Tajikistan at 950 m above the sea level. The hillside has a slope of 12-25%. Soil is a moderately eroded dark sierozem, heavy silt loam, with organic matter content below 0.9%, and soil bulk density around 1.30-1.45 g cm⁻³. In Tajikistan, dark Sierozems occupy 750,000 ha of land, almost 90% of them being eroded.

This is a semi-arid rainfed zone with average annual precipitation around 500 mm. Most of the precipitation falls during winter and spring with low intensity. This results in soil moisture shortage in the summer. Average monthly temperature in January is 1.5° C and in July 23-26° C. Duration of the vegetation period is up to 210 days. The sum of effective temperatures reaches 4000° C, which is sufficient to grow early varieties of grapevines, apples, apricots, melons, and cereals.

Boykozon farm is located in Tashkent province of Uzbekistan at 525 m above the sea level. The area is predominantly hilly. The climate is extremely continental with average annual temperature of 14.3° C. Mean annual precipitation is about 500 mm. The soil is typical sierozem, mainly moderate and heavy loam, with low and medium nutrient content; field moisture capacity is 20-22%. Organic matter content is 1.1-1.5% in the topsoil. The soil infiltration rate is 0.2-0.6 mm min⁻¹.

Installation and Sampling

Strip Cropping

A study on effect of strip cropping on surface runoff, soil erosion, and fertility was carried out at the Faizabad experimental site in 2000-2002. Treatments were as follows:

- Winter wheat (sown in blocks),
- Chickpea (top) - sainfoin (bottom) strips,
- Alfalfa (top)-wheat (bottom) strips,
- Alfalfa,
- Fallow, and,
- Winter wheat (top) and alfalfa (bottom) strips. Treatments were replicated three times on 200 m³ (20 x 10 m) plot area with 14-21% slope. Flow and soil erosion measurements were taken during the rainy season, mainly in April and May.

Mulching and Supplemental Irrigation

The experiment was laid out at Fakhrabad site, Tajikistan, in 2001 to grow grapevines, forest and fruit trees on terraces with the following mulching treatments:

- Control,
- Mulching with black plastic film,
- White thick film,
- White thin film,
- White thin film and N,
- Plant residues.

The following species were planted on the terraces: cherry and plum saplings with winter wheat as an inter-crop; grapevines in two rows; walnut saplings; and pine trees. Mulching was applied over the saplings on a 50 x 50- cm area. Supplemental irrigation for walnut and pine tree saplings was applied at a rate of 3 liter per sapling twice a month from July to October. The experiment was laid out in three replications. In 2002, an experiment was laid out with the plum and walnut saplings with the following treatments:

- Supplemental irrigation (SI) alone,
- SI and mulching (hay),
- SI, mulching (hay) and manure,
- Control (no mulching, no SI).

Mulching was applied under trees on a 50 x 50-cm area around saplings. Starting from July 2002, supplemental irrigation was practised three times in a month in the afternoon, with 3 liters of water applied each time to the plum and walnut saplings.

Improved Furrow Irrigation Technology

The following irrigation technologies were tested at the sloping site of Boykozoon farm in Uzbekistan,

- Joyak (zigzag) furrow irrigation,
- Contour irrigation,
- Traditional irrigation along the slope (control),
- Traditional irrigation with application of 48 kg ha⁻¹ polymer K-9. These technologies were tested for application of supplemental irrigation of winter wheat during 2000-2002. Joyaks are zigzag furrows cut across the slope. The furrows' depth was 20-22 cm.

During the 1999-2000 and 2001-2002 seasons, the widths of the horizontal section of the zigzag were: 2.0, 2.5, and 3.0 m. Zigzag furrows of 1.4 and 2.8 m wide were tested in the 2000-2001 season. Contour irrigation was tested during 2001-2002 season only. Soil moisture was monitored in the root zone during the crop season to determine the irrigation requirement.

RESULTS

Strip Cropping in Sub-Humid Zone

The strip cropping significantly reduced surface runoff and soil erosion in the slopes (Fig. 1). The highest runoff and soil erosion in the spring was observed from wheat crop grown in blocks. Runoff and soil erosion reached 277 m³ ha⁻¹ and 4,444 kg ha⁻¹, respectively. Application of strips, i.e., chickpea (top) and grasses (bottom), or alfalfa (top) and wheat (bottom), reduced runoff and soil erosion by 25% and 10%, respectively. The strip fallow or wheat (top) and grasses (bottom) reduced surface runoff and soil erosion by 50% and 30%, respectively. Runoff and soil erosion under alfalfa was 36% and 46% less than wheat.

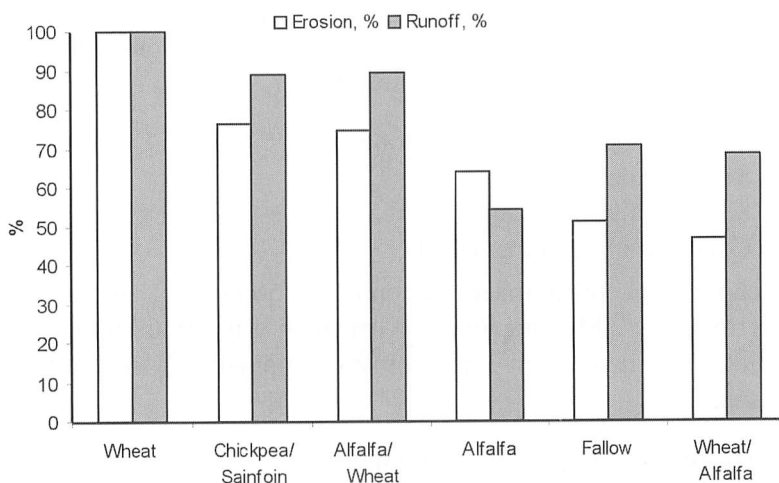


Fig. 1. Runoff and soil erosion under different cropping at the Faizabad site (average for 2000-2002).

The low content of mobile nutrients was another limiting factor for crop yields. Data during 2001 revealed that in early spring there was low nitrogen availability in the 0-50-cm soil layer under wheat sown in blocks (61 kg ha^{-1}) and high under strip sowing (135 kg ha^{-1}). In the comparatively wet 2002, the N content amounted to 55 kg ha^{-1} under alfalfa, 69 kg ha^{-1} under strip cropping, and 166 kg ha^{-1} under fallow, which indicated that under fallow, organic N decomposes and is not used because of the absence of vegetation. At the end of the growing season, there was more mineral N under strip sowing compared to block sowing.

There was low content of P and moderate level of K in the soil. Reduction of mobile P and K content during May was observed in all treatments. During the wet spring of 2002, P and K availability was higher. Under all cropping systems, mobile P reduced by the end of the growing season by about 15%. As to exchangeable K, there was no significant change during the season.

Crop yields were dependent on weather and farming practice. In dry period of 2000, yield of food legumes (chickpea) was low ($0.44\text{-}0.48 \text{ t ha}^{-1}$). Strip cropping affected the winter wheat yield positively (Table 1).

Table 1. Crop yields in moderately eroded brown carbonate soil as affected by strip cropping.

Treatments	2000	2001	2002	Average
	-----t ha ⁻¹ -----			
Winter wheat (block sowing)	0.72	0.84	1.25	1.04
Chickpea/ sainfoin ¹	-	0.73	0.85	0.79
Alfalfa/ winter wheat ²	-	1.02	1.55	1.28
Alfalfa in first year	2.77	2.88	3.57	3.22
Alfalfa in second year	-	6.43	11.35	8.89
Winter wheat/alfalfa ²	-	0.92	1.39	1.15

¹ yield of sainfoin; ² yield of winter wheat

Winter wheat yield was rather low in 2002, even with good rainfall. Planting wheat in strips with alfalfa is improved yield by 11-23%. Higher wheat yield occurred on strips placed down the slope because of more moisture available. Alfalfa yield was good, increasing almost threefold in the second year. Sainfoin was unsuitable forage legume compared to alfalfa. Low content of organic matter and nutrients was the main reason for low crop yields. The results of this study indicated that strip cropping in the sub-humid zone could be efficient method to reduce soil erosion, prevent reduction of soil fertility and increase yield of different crops.

Mulching and Supplemental Irrigation

Soil Moisture Content Under Mulches

Under control without mulching, around grapevines saplings, the soil moisture storage on 20 July amounted to 20% of the initial storage on 27 April (Fig. 2). Soil moisture storage was 70%, 30%, 10%, and 5% higher as compared to control when soil was mulched with black plastic film, plant residues, white thick plastic, and white thin plastic, respectively. Mulching with black film and plant residues provided considerable water saving compared to control, which amounted to 700 and 300 m³/ha, respectively. Although soil moisture storage was higher under black film, plant residues proved to be more economical.

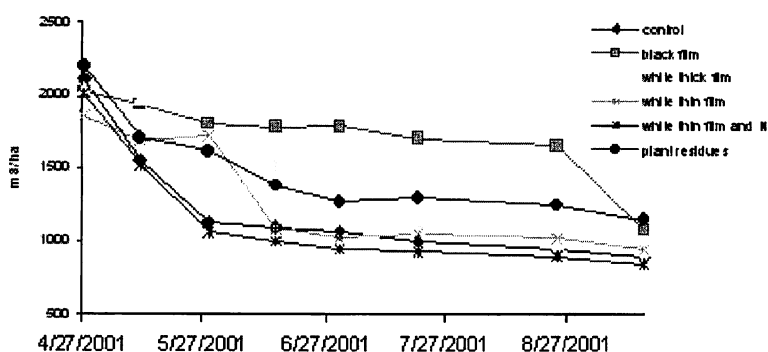


Fig. 2. Soil moisture storages under grapevines as affected by different mulches.

Spring of 2001 season was very dry. Soil moisture storage in the beginning of July fell below 50% of the field capacity. Therefore, to prevent the withering of saplings, supplemental irrigation was applied to walnut and pine tree saplings at the rate of 3 liter per sapling, twice a month from July to October. It improved soil moisture and, as a result, survival rate of saplings was increased (Table 2).

Table 2. Survival rate of walnut saplings as affected by different mulches and supplemental irrigation.

Mulches	Total saplings	July		October	
		Soil moisture	Survival	Soil moisture	Survival
	No.	m ³ ha ⁻¹	%	m ³ ha ⁻¹	%
Control	17	1090	43	580	32
Plant residues	30	1180	66	830	60
White thin plastic film	30	1260	71	880	65
Black plastic film	30	1390	86	840	70

Data obtained during July 2001 before supplemental irrigation indicated that soil moisture storage using mulching with plant residues and white and black plastic films were higher by 8, 16 and 27% as compared to the control (no mulching), respectively. As a result, survival rate of walnut saplings increased by 53, 65 and 100% compared to the control, respectively. By the end of vegetative growth in October 2001, soil moisture storage was 43-52% higher with mulching and supplemental irrigation compared to the control. The survival rate of the irrigated walnut saplings with plant residues, white and black plastic films was 88, 103 and 118% higher, respectively, than at the control.

The observations in 2002 indicated that starting from May, the influence of the mulches became obvious, especially in the topsoil. During May-July, the difference in soil moisture storage in the 0-50 cm soil layer was considerable among the three treatments. When mulching was combined with irrigation, soil moisture content at the 0-50 cm and 50-100 cm layers was greater compared to irrigation alone by 569 and 993 m³ ha⁻¹, respectively. This difference almost disappeared by August. Manure saved additional 40-241 m³ ha⁻¹ of soil moisture in the 0-50 cm soil layer. Irrigation in combination with mulches and manure provided the minimum required soil moisture for growing tree saplings and also increased their survival rate.

Due to poor survival of saplings in dry season of 2001, withered saplings were replanted in March, 2002. During the summer of 2002, all saplings received irrigation except the control. By 1 August, 2002 the survival rate of the saplings of plums, grapevines, walnuts and oleaster received irrigation exceeded 92%.

Joyak and Contour Irrigation Technology

The first two of the three study years were dry for winter wheat production. Precipitation was 380 and 345 mm during 1999-2000 and 2000-2001, respectively. Three irrigations were applied with the rate of 1,200-1,300 m³ ha⁻¹ each. The data revealed that traditional irrigation along the slopes resulted in significant losses of water and fertile soil (Table 3).

Surface runoff was 28% of water applied under traditional irrigation. Water-use efficiency was 20% higher under rainfed conditions compared to traditional furrow irrigation. Application of 2 to 3-m wide joyaks resulted in 14-15% of water saving for irrigation due to reduced surface runoff. Yield of winter wheat increased by 40-45% compared to the control. Moreover, the efficient water-use index increased by 51-55% compared to the control. Soil erosion was reduced by more than five times under joyak irrigation. Results of the 2000-2001 season indicated that the 1.4 m joyak spacing was much less suitable compared to the 2.8 m spacing. During the year 2001-2002, 592 mm of precipitation was recorded. Hence, irrigation was required only in the beginning of June (Table 4).

Table 3. Efficient water use index in winter wheat (1999-2000, 2000-2001 seasons).

Parameter	Rainfed	Control	Joyak furrow irrigation, m				
			2.0	2.5	3.0	1.4	2.8
Yield, t ha ⁻¹	1.94	3.04	5.10	4.80	4.71	3.54	4.65
Precipitation, m ³ ha ⁻¹	3800	3800	3800	3800	3800	3450	3450
Irrigation, m ³ ha ⁻¹	0	3695	3343	3559	3442	3055	2900
EWU, kg m ⁻³	0.51	0.41	0.71	0.65	0.65	0.54	0.73
Soil erosion, t ha ⁻¹	-	5.88	0.72	0.63	0.66	0.33	0.25
LSD5% = 0.6 t ha ⁻¹							

¹ These treatments were tested only in 2000-2001, ² EWU= Efficient Water Use index.

Table 4. Efficient water use index in winter wheat during 2001-2002 season.

Parameter	Rainfed	Control	Joyak furrow irrigation, m			Contour irrigation
			2.0	2.5	3.0	
Yield, t ha ⁻¹	3.23	4.99	5.68	6.07	6.27	6.05
Precipitation, m ³ ha ⁻¹	5920	5920	5920	5920	5920	5920
Irrigation, m ³ ha ⁻¹	0	1186	1135	1050	1038	1028
EWU1, kg m ⁻³	0.55	0.70	0.81	0.87	0.90	0.87
Soil erosion, t ha ⁻¹	-	1.20	0.08	0.04	0.02	0.10
LSD5% = 0.32 t ha ⁻¹						

¹EWU= Efficient Water Use index.

The joyak and contour irrigation technologies increased the yield of winter wheat by almost 20-25%, compared to the control. Efficient water use index was increased by 24-29%. Heavy rainfalls resulted in significant surface runoff in the area. That is why the efficient water- use index was lower under rainfed conditions compared to the control. Remarkably, soil losses due to erosion were reduced from 1.2 t ha⁻¹ for the control to 0.02-0.08 t ha⁻¹ under joyaks and to 0.10 t ha⁻¹ under contour furrows. Thus, irrigation by joyak and contour furrows almost completely controlled the soil erosion.

The joyak irrigation technology greatly reduced the losses of fertile soil layer. The soil moisture profile was uniform over the entire furrow. Irrigation continued without tail water, and water use efficiency was increased. Irrigation during the night also became easier. Absence of mechanisms for making joyaks appears to be major limiting factor for wide adoption of this technology. Two-meter-wide joyaks were found optimal in the dry 1999-2000 season and the 3.0-m joyak in

the wet 2001-2002 season. This may be a consequence of making joyaks manually, 20 cm deep, in the 1999-2000 season and with a tractor, 25-27 cm deep, during the following years.

Portable 1.5m-long chutes were designed to improve uniformity of jets into contour furrows in sloping areas. Adjustable outlets allowed optimization of jet discharge to each furrow in accordance with the slope. The maximum discharge of the portable chute was 7.5 liter/sec. With a closed outlet, the portable chutes were used for transit water delivery to lower tiers of the irrigated plot. If necessary, portable chute kits can be assembled of any required length. Water was delivered into the chute every 50 m with flexible hoses.

During the whole trial period no breakdowns or failures of PCh-50 were registered. The following advantages of PCh-50 were noted: *simple design; reliable performance; and uniform supply and savings* of irrigation water. The portable chutes allowed farmers to easily organize their irrigation schedule. The set installation time was short (30 min) and did not require any special skills. The replacement of parts can be done without special devices.

Economic Assessment

Expenses for purchasing seeds and fertilizers amounted to US\$ 75 ha⁻¹ using the traditional practice and US\$ 133 ha⁻¹ using polymer K-9. The cost of polymer K-9 was equal to 36% of the input cost. Expenses related to growing winter wheat using joyak and contour irrigation included the cost of portable chutes and additional labor work to make joyaks.

The data obtained indicated that the share of inputs in the total cost of production ranged from 39% for 2-m wide joyak to 69% for traditional irrigation with the polymer application. Labor cost varied from 6% for polymer use to 31-35% for joyak technology, which was very labor costly. The research revealed that wide dissemination of the joyak technology is dependent on mechanization of the process of making joyaks. Combination of conservation soil tillage practices, supplemental irrigation and joyak technology can promote adoption of this technology by farmers in the region, it does, however, require on-farm testing.

In general, there was no significant increase in the net profit due to contour or joyak furrow irrigation compared to traditional furrow irrigation. In spite of the fact that these technologies increased yield of winter wheat by about 1.0 ha⁻¹ and that the irrigation rate was reduced by 14-15%, farmers' net profit increased only by US\$ 11-24 ha⁻¹. This is because of the low State procurement price for wheat and free water supply that significantly reduced advantages of joyak and contour irrigation. More than half of the wheat grain produced was bought by the State for half of the market price. Obviously, therefore, the farmers had no apparent benefits from water saving under existing water and agricultural policy. Reduced losses of fertile topsoil caused by erosion under joyak and contour irrigation are likely

to have a positive long-term effect. However, farmers had little interest in soil fertility management due to existing land tenure system.

SUMMARY

Following testing in the sloping areas of Tajikistan and Uzbekistan, various water-saving technologies could improve water-use efficiency and reduce soil erosion in sloping areas of Central Asia. The results of the research activities support the following conclusions:

1. Strip cropping of wheat and alfalfa along the slopes could reduce runoff and erosion under sub-humid conditions.
2. Use of plant residues for soil mulching could be an economical preposition to maintain soil moisture storages under young fruit trees in semi-arid rainfed conditions. However, supplemental irrigation may still be needed in summer to improve survival rates of the saplings.
3. Joyak (zigzag) furrow irrigation can improve yield and water-use efficiency and reduce soil erosion in sloping areas, but would require considerable manual operations. At the same time, irrigation by less labor intensive contour furrows with designed portable plastic chutes will provide the water and soil conservation effect.
4. Wide on-farm dissemination of the water-saving technologies in irrigated areas is restrained by some institutional constraints. Existing state procurement system and free water delivery in Uzbekistan are significantly reducing the possibilities of adoption of water-saving technologies. Farmers have limited interest in soil fertility conservation in both rainfed and irrigated areas, especially when they do not have land ownership rights.

Drainage Water Reuse for Agricultural Production in Central Asia

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ABSTRACT

Drainage water is an important source of water for agricultural production in Central Asia. At present, drainage water from irrigated areas is being diverted to rivers and causing a salinity increase downstream. New strategies of drainage-water utilization for agricultural production could be developed in the region to arrest this process. During 2000-2002, different approaches of drainage-water reuse were tested in diverse agroecological conditions. Sub-irrigation was tested in areas with low saline groundwater in Fergana Valley, Uzbekistan. Closing outlets of horizontal pipe drainage system resulted in increased soil moisture content and reduced number of irrigations, and saved about 1000 m³ ha⁻¹ of surface water. Studies using drainage water for irrigation of shelterbelts were conducted in a zone with wind erosion in western

part of Fergana valley. Utilization of drainage-water for irrigation of shelter-belts increased water supply of the main crop by 10%, thereby prevented yield reduction and soil erosion.

A bio-drainage system was established at an experimental site in the Vaksh Valley, Tajikistan. Poplar and willow were found to be highly effective species for the bio-drainage system. Barley had highest water-use efficiency at salt-affected areas and was the most salt-tolerant grain crop. Areas along irrigation canals and tail-water drains have rather favorable conditions to grow willow; bio-drainage technology requires a long period for establishing and having a land reclamation effect. The drainage system has become sustainable with minimum environmental impact, and is socially sound and economically acceptable.

Establishment of bio-drainage systems appears to be economical and deployable under the current conditions compared with rehabilitation of technical drainage systems. Alternating fresh and drainage water for irrigation of winter wheat in sandy soil in Turkmenistan. Increased efficiency of water use by 10% higher compared to drain-water use. The data obtained showed, that alternating water sources reduces yield losses during dry years.

INTRODUCTION

Low water-use efficiency, which is typical for Central Asia, causes returns of 30-40% of water used for irrigation to the water bodies, with deterioration in quality. In the Aral Sea Basin, drainage flow amounts to 30 out of 80 km³ of water diverted for irrigation. Underground water accumulation makes up the other part of the water losses in the irrigated zone of Uzbekistan and amounts to 24 km³ as ground water storage. More than half of this water is slightly saline with total dissolved solids (TDS) below 3 g L⁻¹.

Drainage-water utilization practices in the region mainly depend on the quality of the drainage-water and availability of fresh water. In the upstream areas, drainage-water (TDS below 3 g L⁻¹) is usually discharged to the rivers. Farmers use drain water for irrigation only during dry years. In the middle and down stream areas, salinity of drainage-water reaches 5 g L⁻¹ or more. The drainage-water is discharged partly to river beds and partly to the natural depressions such as Arnasai in the middle stream of Syr-Darya River and Sarykamysh in the downstream area of Amu-Darya. This practice contributed to increased salinity in the flow of rivers and irrigated lands in the Aral Sea Basin.

In the 1930-1940s, water in the downstream area of both the rivers was not saline (TDS 0.3-0.6 g L⁻¹). By 1980-1990s, within 50 years, the river water salinity increased three times, resulting in an increase of salt accumulation in irrigated

areas. For example, in Turkmenistan, located in the middle and downstream reaches of the Amu-Darya, 1.6 million ha or 89% of the cropland has become salt-affected. In Uzbekistan, 2.3 million ha (53% of the irrigated area) is now prone to salinization. Saline area is widespread in south Kazakhstan and Tajikistan. Obviously, therefore, it is imperative to develop new methodologies for drainage water utilization.

Use of drainage water for irrigation in Central Asia was extensively studied by Kovda and Yegorov (1958), Rahimbaev and Ibragimov (1978), Usmanov (1982), Ramazanov and Yakubov (1988), Mirzaev and Karimov (1989), Yakubov (1990), and many others. Cotton was the main crop under irrigation by drainage water. However, research results of some authors were somehow contradictory. Kovda and Yegorov (1958) reported that use of drainage water for irrigation would cause irreversible changes in soil, while Mirzaev and Karimov (1989) recommended utilizing drainage water in its primary formation zone.

Increase in the area under irrigated winter wheat has changed the drainage flow pattern. The drainage volume has increased in the spring and has decreased in the late summer. Irrigation of winter crops has also changed the quality of drainage flow, hence requiring reconsideration of existing drainage water utilization practices.

After disintegration of large State farms, small farmers radically changed their attitudes towards soil and water management. A small farmer can cultivate soil more precisely and reconsider ways of soil salinity management. At present, however, farmers have limited resources to maintain expensive drainage systems. Therefore, the objective of this research was to provide farmers with economically sound and appropriate technologies for utilization of drainage water.

Tested Technologies

Sub Irrigation.

Closing of outlets of the horizontal pipe drainage system allowed regulating shallow groundwater table and increasing water supply of crops during dry years. This technology was tested at the Fedchenko site, Fergana Valley, Uzbekistan.

Drainage Water for Irrigating of Shelterbelts.

The dense shelterbelts in zone of wind erosion require significant amounts of water for irrigation. Drainage water reuse for irrigation of shelterbelts promotes the diversion of surface water for main crops. This technology was tested at the Dustlik farm, Fergana Valley, Uzbekistan.

Bio-drainage.

The practice of irrigation in the Vahsh Valley showed that horizontal drainage system was not able to maintain groundwater levels because of intensive lateral

underground inflow. Maintenance of the vertical drainage, however, proved to be very costly. Under these conditions, establishment of tree plantations and growing of salt-tolerant crops will reduce pressure to the horizontal drainage and will promote saline soil reclamation. This technology was tested at the Karalang site, Vahsh Valley, South Tajikistan.

Alternating Drainage and Surface Water .

In most cases, crops are sensitive to salinity during the first phases of growth and become more tolerant at final stages of their development. Therefore, alternating water sources of different quality can reduce influence of salinity on yields of crops. This technology was tested for irrigation of winter wheat at Vatan farm, Turkmenistan.

METHODOLOGY

Study Areas

The **Fedchenko** site, located in the Fergana Valley, Uzbekistan, has an arid climate. Rainfall occurs mainly during October - May, averaging 170-180 mm, whereas average monthly temperature ranges from -1.7°C in January to 19.7°C in May. The soil is a heavy clay loam, with topsoil organic matter content around 2%, potassium 1.4%; and soil bulk density of 1.3 g cm^{-3} .

The **Dustlik** site, located in the western part of the Fergana Valley, is characterized with strong winds reaching $15\text{-}24\text{ m s}^{-1}$, with frequency of 40 days a year. The soil is a meadow sierozem, with groundwater table at 1.5-2.0 m. Soils are slightly and moderately saline, with low topsoil organic matter content varying from 0.7-0.9 %.

The **Karalang** site is located in the Karalang depression. The climate is arid, with sum of effective (over 10°C) temperatures around $2800\text{-}3000^{\circ}\text{C}$. Annual precipitation rate is 250-300 mm, whereas potential evaporation goes up to 1200 mm/year. The geological profile is presented by a two-layer structure: upper fine soil of loamy clay sediments, as thick as 6-11 m, underlaid by alluvial gritty-coarse gravel sediments. Soil bulk density is around $1.23\text{-}1.28\text{ g cm}^{-3}$ in the topsoil, while the groundwater table is at 1.0-2.0 m depth. The TDS of groundwater is around $4\text{-}5\text{ g L}^{-1}$, and the salinity type is chloride- sulfate.

The **Vatan** site in Turkmenistan is located in desert arid climate with an average July temperature of 30.7°C . The annual precipitation is 150-220 mm, whereas the evaporation rate from an open water surface is more than 1500 mm. Duration of the frost-free period is up to 286 days, with the sum of positive temperatures around 5800°C . The soil is sandy, slightly saline, with soil bulk density of 1.45 g cm^{-3} . The groundwater table is about 2 m deep, with salinity about $2.5\text{-}3.0\text{ g L}^{-1}$, whereas the TDS of the irrigation water is below 1.0 g L^{-1} .

Installation and Sampling

The outlet of the horizontal drainage system was closed on a 1.7 ha-area, whereas surface irrigation (control) was applied on a 2.3-ha area. Superphosphate was applied in September at a rate of 500 kg ha⁻¹ followed by ploughing. Winter wheat "Umanka" was planted at the beginning of October using a seed rate of 220 kg ha⁻¹. Nitrogen was applied at the rate of 150 kg ha⁻¹ during tillering stage and 170 kg ha⁻¹ during the jointing stage. The outlet of the horizontal drainage pipe was closed at the beginning of April 1, 2001, resulting in an increase in the groundwater level. Irrigation was initiated at 70% of field moisture capacity. The groundwater level was monitored through observation wells. Apparent soil electrical conductivity (EC) was measured during October, 2001 and March, 2002 with an EM38 instrument.

Drainage-water reuse for irrigation of shelterbelts was studied at the Dustlyk site in the area prone to wind erosion. In 1970-1980s, two- and three- row shelterbelts were established to control wind erosion. The distance between shelterbelts was varied depending on soil type. On sandy soil, shelterbelts were established 100-120 m apart at right angles to strong west and southwest winds. On heavy soil, the distance between shelterbelts was 140-200 m. The main trees used were elm, poplar and willow. The studies were conducted on existing two-row and three-row shelterbelts of elm and poplar trees. A new three-row shelterbelt was established from poplar, mulberry, almond, fig, pomegranate and pistachio. Due to a shortage of surface water, drainage water was used for irrigation of the shelterbelts. Studies of bio drainage at the Karalang site, Tajikistan, consisted of three components:

- Selection of suitable crops for salt-affected areas;
- Reclamation of edges of drains and areas along the drain; and
- Planting of trees along canals, drainage lines and thalwegs.

The bio-drainage system, consisted of tree plantations and salt-tolerant crops on irrigated fields, was incorporated into the existing drainage system. Annual and biennial saplings of poplar, pomegranate, cherry-plum, cherry and willow were planted along irrigation ditches and drainage lines. Soil pits for planting of trees were leached at rates of 10, 15 and 20 thousand m³ ha⁻¹ and terraces were established at different levels at the edges of the open drain. At a strip along new open drain tree plantation was established from eight rows of poplar.

Mulching was conducted to control evaporation and to increase soil moisture content. The efficiency of mulching was studied in three row plantings with three replications and following treatments: hoeing (control), plant residues, plastic film, and manure application (70-80 t ha⁻¹). From the second half of August, there

was no irrigation conducted so as to encourage water supply of trees from groundwater. Soil and groundwater were sampled for chemical analysis from each plot.

Alternating drainage, treatments and surface water for irrigation of winter wheat. were as follows:

- Irrigation of winter wheat with surface water;
- Surface water in fall and drain water in spring and summer (alternating water sources);
- Irrigation of winter wheat with drainage water. In fall of 2001 plowing was conducted 25-27cm deep. After soil leveling, pre-sowing irrigation was applied at rate 1500-1600 m³ ha⁻¹. Prior to planting, manure was applied at rate 30 t ha⁻¹. Nitrogen was applied twice at a rate of 60 kg ha⁻¹ each time. The seed rate was as high as 180-200 kg ha⁻¹. Furrows were cut 90 cm wide.

RESULTS

Sub Irrigation

In mid-May, almost one and a half month after closing the drain outlet, the groundwater table was 1.0-1.2 m below the surface at the distance of 25-50 m from the regulated drain, as compared to 1.6-1.7 m in the control part of the field. Only three irrigations were applied as compared to four for the control, totaling about 3,000 m³ ha⁻¹. Sub-irrigation allowed a saving over 1,000 m³ ha⁻¹ of surface water.

A high correlation was observed between the yield of winter wheat and the distance from the regulated drain. Maximum wheat yield was obtained at 25 m from the regulated drain. A further increase in the distance from the drain resulted in yield reduction. Yield of winter wheat was 8.0 and 6.7 t ha⁻¹ at 25 and 100 m from the drain, respectively. This was also reflected in the number of grains per head, which were 39 at 25 m from the drain and 35 at 100 m.

Due to high rainfall in the spring of 2002, the groundwater table rose to 50 cm below the surface within 100 m of the regulated drain. Consequently, only two irrigations were required at the sub-irrigation site, whereas three irrigations were applied to the control. In 2001, the water saving is amounted to about 1,000 m³ ha⁻¹.

Increased share of groundwater in wheat water supply increased the grain yield, particularly within 75 m from the regulated drain (Fig. 1). Within 25-50 m from the drain, yield of winter wheat increased by 0.5-0.4 t ha⁻¹, respectively, compared to control. However, water losses were increased because of shallow groundwater table.

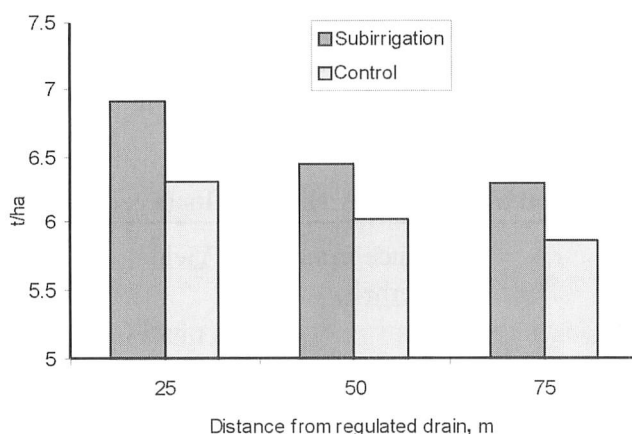


Fig. 1. Yield of winter wheat under sub-irrigation.

The area close to the regulated outlet had increased salinity because of over-moistening and high evaporation. The survey results reflected an increased shallow groundwater table during the spring of 2002 due to the closing of the drain outlets. There was a high correlation between apparent soil electrical conductivity measured by electromagnetic method and groundwater level ($r=0.89$). This correlation may indicate that the EM device could be used to measure the shallow groundwater fluctuation level below the soil surface. The use of EM for monitoring soil salinity in the presence of a shallow groundwater requires further research before wide application of these results.

Drainage Water for Irrigating Shelterbelts

Shelterbelt studies were conducted at the Dustlyk site on sandy and sandy loam soils prone to sulfate salinity. New three-row shelterbelts were established on a loamy soil. Groundwater table was 1.0-1.6 m deep with TDS from 1.0 to 3.0 g L⁻¹. TDS of drainage water was around 2.5 g L⁻¹, concentration of SO₄²⁻ was 1.15 g L⁻¹, a Na⁺ and Ca²⁺ was 0.3 g L⁻¹.

On average, for 2001- 2002, irrigation rate of two row-shelterbelts amounted to about 4,090 m³ ha⁻¹, three row- shelterbelts about 4,270 m³ ha⁻¹ and new ones 3,200 m³ ha⁻¹. The shelterbelts were 10 m-wide each at two sides of the 100 m-wide field. Therefore due to drainage water reuse, surface water saved for irrigation of the main crop on an adjacent field came to about 10% of irrigation water (or 320 m³ ha⁻¹ per year).

In March, 2001, at the time of planting, almonds were, on average, 85 cm high. By June 2002, they doubled in height. Fig trees were damaged by frost in

March, but they re-grew during the summer. Good growth rates were observed for poplar, pomegranate and pistachio. Similar data were obtained for earlier established shelterbelts. The protective action of the existing shelterbelts was evident. The shelterbelt increased cotton yields within 50 to 60 m zone behind the trees (Table 1).

Table 1. Yield of cotton as affected by shelterbelts (average for 2001-2002).

<u>Shelterbelts</u>	<u>Distance from shelterbelt,</u>	<u>Yield</u>	<u>Yield increase</u>
	m	t ha ⁻¹	%
Old two-row	75	2.5	0
	50	3.1	24
	25	3.4	36
Old three-row	75	3.0	0
	50	4.0	33
	25	4.1	37
Newly established three-row (2001)	75	3.0	0
	50	3.2	9
	25	2.8	-6
Newly established three-row (2002)	75	4.5	0
	50	4.6	3
	25	4.8	7

¹ Cotton was sown in 2001 and winter wheat in 2002.

Analysis of variance indicated that yield data were significant (LSD=0.18 t ha⁻¹) for 2002 and were not significant (LSD=2.24 t ha⁻¹) for 2001. Based on an average for 2001-2002, cotton yield between two-row shelterbelts was 24-36% higher within 50 m from the shelterbelt compared to the control at 75 m. The cotton yield between three row-shelterbelts was 33-37% higher in the 50 m zone protected by shelterbelts. The protective action was not observed on cotton grown between the newly established shelterbelts. There was no major influence of the shelterbelt on the performance and yield of wheat.

The electro-magnetic induction method applied for the salinity survey in 2002 showed a high correlation ($r=0.86$) between the apparent soil electrical conductivity and the EC of the 1:5 soil-water extract. The data revealed that a salinity problem exists under the shelterbelts and on part of the irrigated field. This could be due to the presence of CaSO₄ in the soil profile.

Salt accumulation at the field edges occurred during previous years and was a consequence of excessive upward water flow, whereas an inverse process was

observed under irrigated crops. Thus, the area under the shelterbelts could be considered as marginal with respect to cropping land. Utilization of drainage water for irrigation of the shelterbelts increased available water for the main crop by 10%, improved cotton yields, and reduced wind erosion.

Bio-Drainage System for Saline Soil Reclamation

The practice of irrigation in the Vahsh Valley showed that the horizontal drainage system was not able to maintain appropriate groundwater level because of intensive lateral underground inflow. Maintenance of vertical drainage, however, proved to be very costly. Under these conditions, establishment of tree plantations and selection of salt-tolerant crops could reduce pressure on the drainage system and may help in saline soil reclamation. Therefore, this approach was tested at the Karalang site of Vahsh Valley in southern Tajikistan.

Bio-drainage or bio-soil reclamation is a practice aimed at controlling the water-salt regime and optimizing soil conditions and depth of groundwater table using specially established plantations of trees, bushes, grasses and crops. Optimal areas for establishment of bio-drainage systems are strips along irrigation canals and drainage networks. Cotton, barley and wheat were grown in 2002 at Karalang site to identify the most suitable crop for the area and the efficiency of water use. Irrigations were given when soil moisture content reduced to 70% of field capacity.

Suitable plants for bio-drainage were crops and salt-tolerant trees with high transpiration capacity and product value. Tree plantations create special geo-chemical groundwater zones. Trees were planted systematically along irrigation canals, drainage and at thalweg zones of the landscape. All willow saplings, planted on non-saline, slightly and moderately saline areas in spring 2001, survived by the fall. The area along tail water drains was found to be most suitable for growing trees, because of lower salinity. High salinity was observed mainly along the open drain system at the thalweg zone. The poplar trees planted along the thalweg zone in March 2002 had a high transpiration and fast growth rate, and grew well in dense stands. Good survival rate of saplings was observed by the fall, Transpiration capacity of trees is presented in Table 2.

The data indicated that the bio-drainage system could be established using mixed tree species, including fruit trees. Poplar proved to be more efficient compared to willow. Since both local species of willow and poplar are sensitive to salinity, the soil is required to be leached with fresh water before planting.

Table 2. Estimated transpiration from bio drainage system at the Karalang site, Tajikistan.

Species	Transpiration, m ³ /tree	1-Row ¹	2-Row ²
-----10 ³ m ³ ha ⁻¹ -----			
Turanga	12	0.3	0.6
Oleaster	8	0.9	1.8
Apricot	33	0.7	1.4
Mulberry	66	1.4	2.8
Poplar	83	6.8	13.6
Willow	91	2.5	5

¹Transpiration of 1 row along irrigation canal and 2 rows near drainage canal,

²Transpiration of 2 rows along irrigation canal and 4 rows near drainage canal,

There are two ways to establish bio-drainage systems: *passive* and *active*. The passive approach is based on the selection of salt-tolerant trees with high transpiration rate. The active approach includes leaching of soil before planting of trees. Establishment of tree plantations along irrigation canals, roads and farm boundaries does not require significant efforts. It is, however, more complicated to establish tree plantations along open drains under the conditions of shallow and saline groundwater and saline soil. The estimated efficiency of bio-drainage system was compared to a control including the open drain and three vertical wells operated nine months during the year. The data revealed that potential transpiration of a bio-drainage system amounted to 9,000 m³ ha⁻¹, which is comparable to the flow of a vertical drainage system and is three times more than flow of an open drainage. Thus, bio-drainage systems appeared to be a sustainable option at the Karalang site.

Soil moisture storage as influenced by mulching was measured in May 2002 (Fig. 4). The plastic film was found to be effective for reducing evaporative losses: the water storage was 19% and 32% higher compared to the control under non saline and moderately saline soil conditions, respectively. Mulching with manure proved to be highly efficient, especially in non-saline conditions. Soil moisture storage under mulching with plant residues was 9% higher than under mechanical hoeing.

Soil salinity was monitored using the EM38 instrument. The correlation coefficient for the apparent soil electrical conductivity in the 0-70 cm layer and the soil extract (1:5) was 0.91. The results of the survey indicated initial stabilization of soil salinity under the trees, especially in the last part of the shelterbelt as compared to the previous period characterized by gradual increase of the soil salinity.

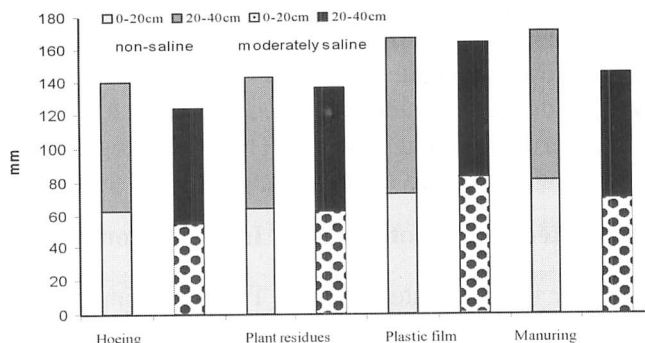


Fig. 4. Soil moisture storages under different mulching options.

The full efficiency of the tree plantation can be realized after 4-5 years, when trees would have proper root system and greater leaf surface. Additional trees were planted on the right hand side of the field due to lateral underground inflow.

Cotton, barley and wheat were sown to examine the suitability of these crops. Irrigation water applied amounted to 6,800 m³ ha⁻¹ for cotton, 2,100 for barley and 2,000 for wheat, respectively. Precipitation received amounted to 120 mm during the growing season of cotton and 250 mm during the growing season of cereals. Upward flow was equal to 1,700 m³ ha⁻¹ having shallow groundwater under cotton and 360 and 315 m³ ha⁻¹ under barley and wheat. Values of efficient water-use index are presented in Table 3.

Table 3. Groundwater salinity and depth in relation to crop yield and water use during 2002.

Crop	Groundwater	Yield, t ha ⁻¹	Yield reduction, %	Crop water m ³ ha ⁻¹	Water index, kg m ³
Cotton	>3 m	2.50	0	8000	0.31
Cotton	<1.0m	1.40	44	9700	0.14
Barley	Non saline ¹	4.30	0	4960	0.87
Barley	Slightly	3.80	12	4960	0.77
Barley	Moderately	2.83	34	4960	0.57
Wheat	Non saline	2.70	0	4815	0.56
Wheat	Slightly	2.37	12	4815	0.49
Wheat	Moderately	1.98	27	4815	0.41

¹ EC 0-2 dS m⁻¹; ² EC 2-4 dS m⁻¹; ³ EC 4-8 dS m⁻¹; ⁴ efficient water unex

The saline, shallow groundwater table reduced cotton yield by 44% compared to the 3-m deep water table. On moderately saline soil, yield of wheat and barley was 12% lower than on non-saline soil, but under moderately saline conditions wheat yields were affected more than barley. Thus, barley appeared to be more

salt-tolerant than wheat, confirming general salt tolerance data (e.g., Maas and Hoffman, 1977). Water was used more productively by barley compared to wheat. Shallow saline groundwater resulted in low water-use efficiency of cotton. The establishment of bio-drainage system appeared to be much cheaper compared to rehabilitation of a vertical drainage system. This technology, however, requires at least 4-5 years to ensure effective land reclamation.

Drainwater Use: Winter Wheat Irrigation on Sandy Soil

The drainage flow from irrigated areas of Turkmenistan amounts to 6.7 km^3 annually. Turkmenistan has developed several projects for drainage water utilization. The most contradictory among them is the project on a Turkmen lake, which has uncertain results. The Turkmen lake of 140 km^3 water volume is to be created by filling the Karashor depression located in the central part of the Karakum Desert. The lake would accumulate drainage outflow from all the irrigated systems of the country. Totally, 2,654 km of drainage networks will be constructed to divert drainage-water from irrigated areas to the 720-km long Master Drain.

The area of over 800,000 ha suitable for irrigation is in the zone of construction of the new Master Drain. The soils there can be successfully used for growing cotton, alfalfa and other crops, if irrigation water is available and if wind erosion is controlled. In this area, groundwater is usually 1.0-3.5 m deep and TDS of groundwater is in the range of $1.5\text{-}3.5 \text{ g L}^{-1}$, while that of drainage water varies widely from 2.0 to 42.0 g L^{-1} .

In most cases, the TDS of drainage waters are between 3 to 5 g L^{-1} (57%). A small portion (21%) of drainage water has TDS of $2\text{-}3 \text{ g L}^{-1}$, whereas one-fifth of the drainage water has a TDS above 5 g L^{-1} . Considering diverse quality of drainage flow, it was proposed to utilize drain-water inside the irrigation zones. The idea was tested at an experimental site located around 40 km from Ashgabat.

Water Quality at the Experimental Site

Karakum Master Canal was the source of water for irrigation at the experimental site. Water salinity in the canal varies with time, generally being low (around 600 mg L^{-1}) in July -August and high during winter (800 mg L^{-1}). Thus, low salt concentration occurs during hot weather and high salt concentration occurs during cold weather. This regime is convenient for irrigation and eliminates combined influence of salinity and temperature at the same time.

Drainage-water quality had a similar pattern, with maximum salinity during fall-winter season. TDS of the drainage flow was maximum ($2.5\text{-}4.0 \text{ g L}^{-1}$) during fall and winter, and minimum ($2.0\text{-}2.5 \text{ g L}^{-1}$) during May-July. This was observed because saline groundwater was the main source of drainage flow during fall and

winter, and irrigation water during summer. An assessment of the surface and drain waters by the Alekin method (Alekin, 1970) indicated that the Karakum Master Canal has good quality water suitable for irrigation. The drainage coefficient was around 6-12 during spring-summer season, and decreased to 3.5 during the fall, which indicated poor water quality. That is why water sources for irrigation were alternated, using surface water in the fall and drainage in spring-summer season.

Applied Irrigation Schedules: Winter Wheat Yield

Pre-sowing irrigation was given during the fall of 2001, and four irrigations were applied during winter wheat growing season. The total rate of irrigation for surface, conjunctive, and drainage water amounted to 4,900 m³ ha⁻¹, 5,100 and 5,300 m³ ha⁻¹, respectively. Irrigation rates were 10-15% higher using drainage water compared to the control. Drainage water was pumped from an open drain and surface water was diverted from the Karakum Master Canal. Due to the rainy weather in the fall of 2001 and rare shallow drainage, the groundwater level rose from 1.5 m below the surface to 1.1 m by spring 2002. Irrigation water sources affected wheat yield significantly in 2001, whereas in 2002 it was not significant (Table 4).

Table 4. Yield of winter wheat as affected by different irrigation sources

Irrigation sources	Yield			Efficient index	Water use efficiency
	<u>2001</u>	<u>2002</u>	<u>Mean</u>		
	-----t ha ⁻¹ -----			-----kg m ³ -----	
	2.1	3.3	2.7	0.31-0.45	0.32-0.51
Alternate	1.8	2.6	2.2	0.25-0.34	0.27-0.34
Drainage-water	1.7	2.3	2	0.23-0.27	0.26-0.35
LSD5%	0.24	1.27			

The yield of winter wheat under alternate irrigation water sources was 19% lower compared to irrigation with surface water, and 7% higher as compared to drain-water use. Efficient water use index for alternating water sources was 10% higher compared to the drain-water use, and water use efficiency was 7% higher. In spite of the reduced yield of winter wheat, alternating fresh and drainage water sources will increase available water resources during drought years.

Use of low saline water for irrigation had no substantial influence on the salinity of sandy soil. On an average, soil salinity in the 0-1 m layer for control was 0.22-0.23% of dry soil weight in the fall and by the end of growing season. Under

conjunctive water use, soil salinity during the growing season increased from 0.19% to 0.25%. When drain-water was used, soil salinity was 0.34% throughout the season. This data indicated that the use of drain-water with TDS below 3 g L⁻¹ for irrigation would result in saving of good quality water.

SUMMARY

1. Drainage water is an important resource in Central Asia. Over 30% of irrigation water returns to water bodies with deterioration in its quality. In addition, a significant part of water losses during irrigation is accumulated underground.
2. In the areas subject to wind erosion, drainage water might be successfully used for the establishment of shelterbelts. The use of drainage water for shelterbelts on meadow sierozem soil in the areas with wind erosion will annually save around 500 m³ ha⁻¹ of surface water for irrigation of main crops. Only in Uzbekistan, an area with strong wind, does erosion exceed 500, 000 ha.
3. Poplar and willow trees were highly effective species for bio-drainage systems. Areas along irrigation canals and tail-water drains have rather favorable conditions to grow willow. Shallow, highly saline groundwater and saline soils were found to be serious constraints for establishment of tree plantings along drainage canals. Local soil leaching is required before planting trees in this area.

Bio-drainage practice was found to be effective in conditions with a two-layer geological profile, when loamy clay sediments underlie the alluvial gritty-coarse gravel sediments. It was also found much cheaper compared to rehabilitation of vertical drainage systems, although the technology requires time to get established and to ensure a land reclamation effect.

4. Alternating surface and drainage water for irrigation on sandy soils of Turkmenistan can increase water supply during water-shortage periods and reduce the toxic effect of high salt concentration during salt-sensitive stages of crop growth. This technology can be applied on sandy soil covering an area of about 800,000 ha in Turkmenistan.
5. The use of EM38 as a management tool helps for real-time monitoring of soil salinity and shallow ground water fluctuation and, in turn, for better management decisions for economic farming.

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Harnessing the Soil Resources of Central Asia for Development

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ABSTRACT

Soil is the greatest gift of nature, the source of our richness. Sustainable development depends of many factors, but the most important is enhancing soil quality. There is increasing evidence in Central Asia that human activities are a leading cause of soil degradation erosion, salinization, pollution, and compaction. In this paper, we emphasize some soil conservation technologies in rainfed areas, and approaches to the reclamation of saline soils and for the sustainable use of soil resources in Central Asia.

INTRODUCTION

The total area of the five Central Asian countries is 4 million km². Kazakhstan is the biggest country, covering 68% of this area. The relief in this region is extremely variable, ranging from 300 m above sea level to 7495 m. In the East, there are the Tien Shan and Pamir mountain ranges. The highest mountain of Central Asia is the Peak Somoni, which is located in the northern Pamirs (Tajikistan). In the northeast of the region, there is the second largest crater lake in the world - the Issyk-Kul (Kyrgyzstan). In the southwest, there is the Kara-Kum or "Black Sand" desert, which is one of the largest sand deserts in the world, covering over 80% of Turkmenistan. Another large desert, the Kyzyl-Kum or "Red Sand" desert, extends over Kazakhstan and the north of Uzbekistan. The west of the region is characterized by the depressions of the Caspian Sea. The Aral Sea, in the central western part, is located on the border between Kazakhstan and Uzbekistan. It is known as one of the world's most serious environmental disaster areas.

The climate of the region is *continental*. Average winter temperatures vary between -3°C and 20°C, but can fall below -45°C in the mountain regions of Tajikistan. Average summer temperatures vary between 19°C and 32°C, but often reach 50°C in the southeastern Kara-Kum in Turkmenistan. The average annual precipitation rate of this region is 338 mm, varying from less than 70 mm in the

plains and deserts to 2,400 mm in the mountains of central Tajikistan. The annual renewable water resources of the Central Asia are 206 km³, or 3771 m³ per inhabitant (as compared to 6935 m³ per inhabitant in the world).

Land and Soil Resources

In ancient times, Central Asia already was one of the main agricultural centers of the world. Many Central Asian countries are agricultural countries and their national economies are based mainly on the exploitation of their soils, which are mainly Sierozems (80%), as the primary natural resource. Cotton has been produced for almost a century. Thus, soil productivity recently has become very low. During Soviet times, agriculture was characterized by a high rate of mechanization, heavy use of chemical fertilizers and pesticides, the development of monoculture in the regions, and by the use of excessive quantities of water for irrigation. As a result, soil deterioration became dramatic. Although substantial resources were allocated for agricultural intensification during 1970-'90's, the farm yields in the last decade of transition to open economies have decreased.

Around 11% of the total area in Central Asia is cropland, 64% is rangelands, 4% is forest, 20.4% are other areas. The irrigated area in this region is 21% of the cropland (Table 1). The arable land per capita in Tajikistan amounts 0.08. in Kyrgyzstan 0.28 ha. Therefore the region has to secure sustainable use of our land.

SOIL DEGRADATION

The main factors of soil degradation in Central Asia are the following: soil erosion, landslides, soil compaction, and secondary salinization caused by irrigation.

Table 1. Land use in Central Asia.

	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Total area, ha	267,073	19,180	14,060	46,993	41,424
Cropland, ha	34,978	1,420	860	1,480	4,500
% of total land	13.1	7.4	2.1	3.1	10.9
Rangelands, ha	186,823	9,000	3,550	30,000	20,800
% of total area	70.0	46.9	25.2	63.8	50.2
Forests, ha	9,600	730	537	4,000	1,300
% of total area	3.6	3.8	3.8	8.5	3.1
Other area, ha	35,672	8,030	9,113	11,513	14,824
% of total area	13.4	41.9	64.8	24.5	35.8
Irrigated area, ha	2,300	1,050	718	1,300	4,000
% of crop land	6.6	73.9	74.8	87.8	88.9

More than 25 types of soil are found in Central Asia. The characteristics of some of them are shown in Table 2.

Table 2. Parameters of main soils in Central Asia by vertical zones.

No.	Soil types	Altitude	Wetting depth	Depth of OM (A+B1) horizons.	Profile depth (A+B1+B2)	Organic matter
		M × 100	M × 100	-----cm-----	-	----%---
1.	Sandy-desert	2-3	-- 30	0-10	-	less 0.5
2.	Grey brown	3-4	3-5	10-15	15-25	0.5-0.7
3.	Light Sierozem	4-5	5-7	20-35	30-35	0.7-1.2
4.	Typical Sierozem	5-7	7-10	25-30	30-40	1.0-1.5
5.	Dark Sierozem	7-10	10-12	30-45	40-50	1.5-2.5
6.	Mountain cinnamon calcareous	10-18	12-15	45-50	50-60	2.0-3.0
7.	Mountain light cinnamon calcareous	20-28 29-30	20-25	50-60	80	3.0-4.5
8.	Mountain light cinnamon	12-17 20-28	15-20	50-79	75	2.5-3.5
9.	Mountain cinnamon ordinary	17-18 26-28	20-30	60-100	80-120	4.0-9.0
10.	High mountain meadow-steppe	20-28 31-33	Bed rock	70-80	100-120	6.0-9.0
11.	High mountain steppe	21-39 45	Bed rock	50-70	70-90	5.0-8.0
12.	High mountain desert-steppe	450-470	Bed rock	32	50	4.0-5.0
13.	High mountain desert	470-480	Bed rock	10	10-15	0.4-0.6

Erosion

Most of the territory of Tajikistan is situated on slopes (Table 3). Millions of hectares are subject to soil erosion (Table 4). Our estimates show that soil erosion causes enormous damage not only to agriculture but also to the national economy as a whole. For example, annual losses of fertile soil include 100,000 tons of phosphorus and potassium. The indirect losses expressed in agricultural production constitute around 500,000 tons of nutrients. Our research conducted in the zones severely affected by soil erosion show that during the period of a planned economy (1950-1990) surface erosion of soil, especially medium and strongly eroded ones, increased threefold.

Table 3. Sloping land in Tajikistan.

Slope degree	Total	Arable land	Grassland/badland
		-----%-----	
2	9.1	24.1	6.4
2-5	15.4	40.6	11.0
5-10	12.5	17.3	12.2
10-15	11.4	8.7	11.9
15-20	12.7	6.0	13.9
20-30	21.5	3.3	24.6
30-45	13.8	-	16.3
45	3.2	-	3.7

Table 4. Extent and type of erosion in Tajikistan.

Soil type	None	Low	Medium	High	Water	Windy	Total
	-----%-----						
Grey brown	-	-	-	-	-	100	100
Light Sierozem	15.6	11.8	6.0	4.7	22.5	62.0	24.5
Ordinary Sierozem	20.6	18.8	14.9	13.6	47.3	32.1	79.4
Dark Sierozem	28.0	20.5	28.9	16.1	55.5	16.5	72.0
Sierozemic-meadow	81.0	-	-	-	-	19.0	19.0
Mountain cinnamon	15.7	16.7	33.2	34.4	84.3	-	84.3
calcareous							
Mountain light	15.4	12.3	23.2	32.5	57.9	16.7	84.6
cinnamon calcareous							
Mountain light	7.2	3.7	21.2	67.9	92.8	-	92.8
cinnamon							
Mountain cinnamon	17.4	13.1	25.2	44.3	82.6	-	82.6
ordinary							
Mountain forest-	0.6	13.7	58.4	27.3	99.4	-	99.4
steppe							
High mountain	5.5	13.4	23.4	57.7	94.5	-	94.5
meadow-steppe							
High mountain	0.5	4.2	21.6	44.2	70.0	29.5	99.5
steppe soil							
Total	17.7	14.8	30.1	23.9	58.8	23.5	82.3

The intensification of soil erosion processes occurred due to anthropogenic soil reclamation for agricultural needs, which were usual for all the countries of Central Asia. Over the period of agricultural intensification, the surface of grass-land decreased by 96%, rangelands by 35%, and virgin land by 100%. Instead, the areas of arable land were increased. The eroded soil surface increases every year by approximately 0.8%.

Over recent years, more and more damage is caused by wind. Unfortunately, this form of erosion is almost never considered in Central Asia, although its share is growing due to deforestation and actions violating the natural hydrological balance. The main principle of erosion-protection is a differentiated land management taking into account the soil's susceptibility to wind erosion (Table 5).

Table 5. Distribution of arable land in northern Kazakhstan according to the degree of potential danger of wind erosion.

<u>Total</u>	<u>Low</u>	<u>Moderate</u>	<u>Strong</u>	<u>Severe</u>
	-----10 ³ ha-----			
21781	860	3,277	14,488	3,156

A solution to most of the soil degradation problems could be certain soil conservation technologies, which could be included in the adaptive and preventive strategies now being under development. In the adaptive strategy, we include the policies and actions aimed at diminishing soil degradation rate in the framework of the current farmland and farming practices. In the preventive strategy, we include the policies and actions that transform the traditional farmland into soil regions for *conservation, protection, and reclamation*.

Soil Conservation Technologies in Rainfed Areas

The current system of agriculture carried out on slopes should be transformed to *erosion-protection* agriculture, thus preventing soil erosion as much as possible. Without the adoption of these practices, it is difficult to ensure sustained high yields and to decrease production costs. Agriculture in erosive regions should envisage a special type of farm and some specific agricultural cropping practices to use and most efficiently maintain soil fertility of erosive soils. The control of soil erosion should be tailored to the particular conditions of the territory. Due to the variety of climate, relief, soil, and vegetative cover in different regions, there should be a variety of approaches to using the systems of erosion control.

Our research in the ICARDA Project "On-farm Soil and Water Management for Sustainable Agriculture in Central Asia" covered two approaches. First, we

identified the soil degradation rate for the hydrographic basin in order to find out if this process is intensifying due to natural conditions or anthropogenic factors. Utilizing geographical-comparative, cartographic, laboratory-analytical mathematical-statistical methods, as well as soil processes, modeling and simulation, we identified the soil degradation rates for different regions and for the whole territory of Central Asia.

Subsequently, we experimented with various techniques to reduce soil degradation. Mulching is an important technology for improving soil microclimate, enhancing soil life, soil structure and fertility, conserving soil moisture, reducing weed growth and preventing damage by rainfall (soil erosion) while reducing the tillage rate. Mulching is very important technology for water harvesting (Fig. 1). In rainfed agriculture, good management of water is of great importance, especially when rainfall is too irregular and unfavorable for crop production. Mulching with plastics and plant residues was found useful for the improvement of the water harvesting capacity of the soil and helped the growth of trees in the south of Tajikistan.

In general, good vegetative cover of soil, protection from erosion, organic matter management and guiding the flow of excess water are the most important ways of conserving soil and increasing farm productivity. Mulching increased the soil organic matter and total nitrogen in a soil over the last 15 years by a factor of three (Table 6).

Water run-off may cause considerable soil erosion. For farmers, this means losses of both, production and of the farm's natural resource capital. Using technology of strip cropping, a farmer can minimize the risks of farming and the loss of soil and water resources (Fig. 1).

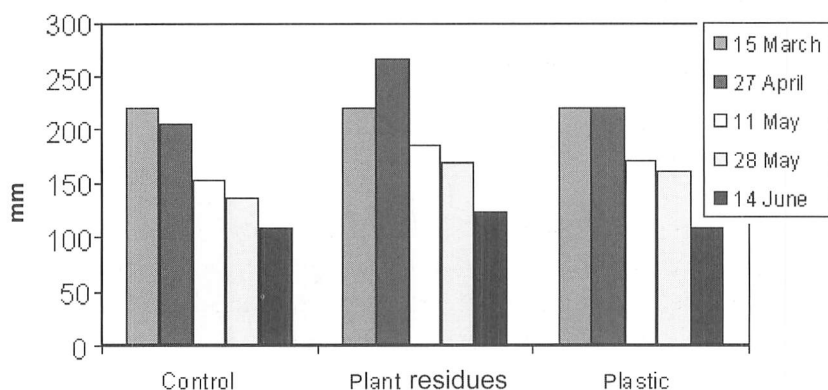


Fig. 1. The influence of mulching on the water harvesting capacity of soil at various times of the year.

Table 6. Changes in organic matter and total nitrogen in a typical Sierozem during 15 years.

Treatments	Depth, ---cm---	Humus		Nitrogen	
		1986	2001	1986	2001
-----%					
Fallow		1.25	0.93	0.099	0.087
	0-30	(47.3)	(34.3)	(3.74)	(3.29)
	30-50	0.72	0.73	0.061	0.060
		(18.0)	(18.2)	(1.53)	(1.50)
Mulching	0-50	0.98	0.85	0.080	0.073
		(65.3)	(52.5)	(5.27)	(4.79)
	0-30	1.28	3.03	0.103	0.125
		(48.1)	(117.6)	(3.87)	(4.70)
	30-50	0.67	2.30	0.056	0.159
		(24.2)	(57.3)	(1.39)	(3.96)
	0-50	0.98	2.66	0.084	0.139
		(72.3)	(174.9)	(5.26)	(8.66)

Lower numbers in each cell (in parenthesis) refer to t ha^{-1} organic matter.

Traditional wheat production on high slopes leads to large losses of soil and water when compared to strip cropping of wheat and grasses or grasses and wheat or legumes and grasses. These systems of using slopes increases the quantity of organic matter in the soil. According our data from the Obi-kiik site, the quantity of humus in the strip-cropped treatments increased from 1.34 to 1.85%. Strip cropping approaches as part of integrated land management that can control soil erosion, improved productivity of farming and conserved natural resources (Fig. 2).

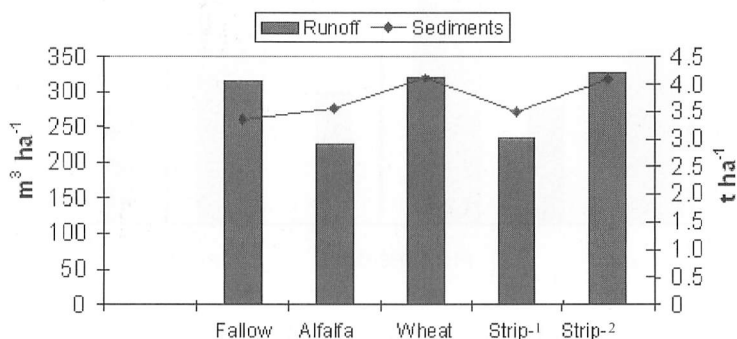


Fig. 2. Runoff and sedimentation (Strip¹=wheat, alfalfa; Strip²=alfalfa, wheat).

Saline Soils

Irrigation is one of the main input factors for obtaining high and sustainable yields of farm crops in Central Asia. Therefore, the area of irrigated soils was increased substantially. However, low efficiency of water consumption in agriculture is one of the biggest problems, as adequate drainage systems were left out from the design. Lack of inputs and destruction of their distribution systems, of irrigation infrastructure and others resulted in salinization, water logging, and overall soil degradation. These are followed by decreasing crop productivity that reaches 50-60%, poor crop quality, and higher energy requirements for pumping. This requires serious attention, because it defines the extent of ecological destructions and the need for reclamation of the irrigated lands in the future.

Nowadays, Tajikistan alone has more than 116,000 ha of saline soils and more than 30,000 ha of waterlogged areas (Table 7). Irrigation and the resulting drainage waters in higher-altitude zones of valleys raised the groundwater level in the lower lying lands and territories, so that it becomes too close (1-2 m) to the soil surface. One of the measures necessary to prevent water logging and salinization in arid and semi-arid areas is the installation of drainage facilities. Drainage, in combination with adequate irrigation scheduling, enables the leaching of excess salts from the plant root zone. Information on salinization through irrigation was given for seven countries, including all five Central Asian countries. The area salinized varied from 5 to 50% of the irrigated area.

Table 7. Saline soils in Tajikistan.

Years	Total irrigated area	Lightly saline	Medium saline	Heavily saline	Total saline areas
-----10 ³ ha-----					
1980	633.8	78.3	20.4	12.1	110.8
2000	703.0	80.0	28.0	8.2	116.2

Development of irrigation systems in Tajikistan has been accompanied by an increasing water use. In the 1980's it was 5.5 km³ yr⁻¹, while now it is 11.2, with water consumption of above 20,000 m³ ha⁻¹ yr⁻¹. Great losses of fresh water have been the negative consequence of ineffective use of irrigation water. As a result, 30,000 ha of irrigated land is affected by secondary salinization and water-logging. In this context, salinization and water-logging are the main challenges in assuring sustainable agriculture.

Reclamation of Secondary Saline Soils

Degradation processes and their various combinations cause different types of damage to the whole territory of Tajikistan. Only few attempts are known to have been made to evaluate the influence of soil salinization on the total cotton production area. According to these estimations, the country annually loses 70-100 thousand tons of cotton, 100-150 thousand tons of grain, 400 M m³ of irrigation water and 2.5 thousand tons of nitrogen and potassium in drainage water. Irrigating of 100-110 thousand hectares of higher-elevation land resulted in an increase of the ground water level and salinization of the soil in the lower located areas. Leaching the salt from soil by furrows was tested in the Bishkent Valley of Tajikistan.

Recommendations for Sustainable Soil Use

A preventive strategy can be implemented under the current conditions of land privatization in Central Asia, which needs to go together with the distribution of land, the new allocation of land with a focus on soil protection which will allow the retention of rainfall as much as possible on the slopes and to store excess water in the soil in a harmless way. Land fragmentation does not make degradation control impossible if it is done according to a long-term state program for nature protection. In that case a lot of obstacles against runoff could be built and erosion processes would not accelerate.

The main means for the improvement of soil protection on agricultural farmland of Central Asia are as follows:

- Utilization of the limited rainfall by using water-harvesting technology.
- Improvement of irrigation method and an increase in water use efficiency.
- Development of plans for the reclamation of saline, sandy, waterlogged and compacted soils.
- Development of landscape-based agriculture, which includes the introduction of new crop rotations, cropping patterns, tillage systems, and fertilization and irrigation regimes.
- Taking highly eroded soils out of the intensive agricultural network for transfer into perennial crops or grasses.
- Soil conservation land-use planning with a well-justified and calculated network of forest belts for the protection of soils with additional hydro-technical actions.
- Full utilization of soil protection capacity of bio-engineering actions in the waterlogged areas.

- True crop patterning on slopes, using contour bunds with perennial grasses, annual or perennial grass belts, growth of grass in between rows of orchards and vineyards.
- Large-scale implementation of non-traditional technologies, such as minimal soil tillage or zero tillage, mulching with plant residues, systems of multiple crops for a better cover of soil and better water regime.

The following priority actions should be undertaken to prevent further soil degradation in Central Asia:

- A mechanism for the implementation of laws on soil conservation should be developed.
- Actions for the transition to sustainable development, including the improvement of economic, social, and environmental conditions should be developed and implemented.
- A national strategy and policy for soil conservation in Central Asia should be developed.
- The availability of small mini soil conservation agricultural equipment for farmers should be ensured.
- Development and implementation of the programs for education, training, and awareness for all categories of the population should be undertaken.

The future use of soils in Central Asia, especially on slopes, depends on the strategy adopted for the development of agriculture. Therefore, the transition to sustainable agriculture is proposed in order to conserve the soil resources in the region.

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Soil Organic Carbon of Central Asia's Agroecosystems

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ABSTRACT

The organic matter status of soil is vital to maintenance of the productive capacity of land and has a modifying influence on the atmosphere, especially with respect to green house gases. Studies in the US, Canada and elsewhere have shown that as much as 40 to 60% of organic matter in many soils have been lost as a result of converting the land from its natural conditions to agricultural production, especially when the soil has been subjected to intensive and repeated cultivation. The intensive cultivation of virgin lands and higher grazing pressure into rangelands in Central Asia has also generally resulted in a substantial decline in organic matter.

As a result of this decline, large amounts of plant nutrients, particularly nitrogen, have been released. Crops, mainly cotton, grown in monoculture with, a high frequency of soil tillage and summer fallow, have relied on the N released from soil organic matter to supply growth requirements. More frequent or continuous cropping, less frequent tillage or conservation tillage, application of organic fertilisers and different agro-industrial composts, and the return of crop residues can help to maintain soil organic matter at a satisfactory level. Perennial forages are effective for maintaining or increasing soil organic matter, and at the same time contribute to economically and environmentally sustainable use of agricultural land.

INTRODUCTION

As in many other arid regions of the world (i.e., the Middle East, North Africa, and Rajasthan), the influence of humans on the environment of Central Asia goes back to antiquity (Babaev, 1992). Numerous artefacts of the Mesolithic and Neolithic settlements are found all over this vast region. Centers of great civilizations repeatedly grew, flourished, and declined during ancient times and medieval history (Baktria, Margiana, Nisa, Merve, Horesm, Bukhara, and

Samarkand). Up into the Middle Ages, various nomadic tribes (Sarmats, Khosars, Huns, Bulgars, Kazakhs, Kalmyks and Mongols) successively came through the area.

The region of Central Asia includes five newly independent countries (the former Soviet Republics of the Soviet Union): Kazakhstan, Turkmenistan, Kirgyzstan, Uzbekistan, and Tajikistan. Arid and semi-arid environments cover about 55% of the land in Central Asia and Kazakhstan. This vast desert region of about 3.5 million (M) km² comprises the entire Turan lowlands and the southern margins of the Kazakh hills.

On its southern and southeastern edges it is bounded by high mountain chains such as the Hindu-Kush, Pamiro-Alay (7450 m) and Tiang-Shan, at 7440 m above sea level. In the southwest, the somewhat lower mountains of the Kopet-Dag allow monsoon precipitation to reach the western slopes of the Tian Shan and Pamiro-Alay. In the north, the Turan Plain descends progressively northward and westward and opens out towards the Pre-Caspian lowland, which is joined with the West Siberian plain via the Turgay Valley.

From the geopolitical standpoint, Central Asia comprises the five states of the Commonwealth of Independent States (CIS), formed in December 1991 after the USSR collapsed: Uzbekistan, Kazakhstan, Turkmenistan, Tadjikistan and Kirgызstan. Desert environments are typical for the first three of them, especially for Turkmenistan where they cover more that 95% of the total territory. Also, the semi-desert of the Pre-Caspian lowlands is the continuation of this area on the southeast of European part of Russia. The Central Asian deserts and semi-deserts have a typical continental climate. Summers are hot, cloudless and dry, and winters are moist and relatively warm in the south and cold with severe frost in

Table 1. Area and population of Central Asia countries.

<u>Countries</u>	<u>Land area</u>	<u>Population</u>				
		<u>1959</u>	<u>1970</u>	<u>1979</u>	<u>1989</u>	<u>1999</u>
	10 ³ km ²	-----Millions-----				
Kazakhstan	2,713	9.3	13.0	1.5	16.5	16.8
Uzbekistan	447	8.1	11.8	15.4	19.9	22.2
Kirgizstan	198	2.0	2.9	3.5	4.3	4.5
Turkmenistan	488	1.5	1.2	2.8	3.5	4.5
Tajikistan	143	2.0	2.90	3.8	5.1	5.7
Total	3,994	23.0	32.80	40.2	49.4	53.8

Source: Kharin and Tateshi (1996)

the north. The area and population of these countries are given in Table 1.

Central Asia (also called Middle Asia by Russian geographers) is located within vast Aralo - Caspian Basin (Kharin and Tateish, 1996). Vast desert and semi - desert plains, piedmont plains and oases of irrigated soils are the main landscapes features of the region. The five new Central Asian countries form a separate geopolitical region. These countries have much in common: the physical environment, economic heritage from Soviet Union, similar traditions in agriculture, and a similar culture and religion, i.e., Islam. The region's population has more than doubled over the last 30 years (Table1).

Distribution of agricultural land by land use types is given in Table 2. Cotton is main cash crop of the region. Irrigated farmland occupies 8.672 M hectares. The production of cotton in 1992 was 315.000 thousands tons in Kazakhstan, 68 in

Table 2. Distribution of agricultural land of Central Asia by land use types.

Land use ¹	Kazakhstan	Kirgyzstan	Uzbekistan	Turkmenistan	Tajikistan	Total
	----- M ha ⁻¹ -----					
Arable land	36.0	0.5	4.1	1.233	822	2.775
Hayland	0.3	0.17	0.12	0.01	0.03	0.6
Rangeland	180.0	5.2	23.1	34.5	3.4	46.3
Total	216.3	5.9	27.4	35.8	4.3	289.7

Source: Kharin and Tateishi (1996)

Kirgyzstan, 6,292 in Uzbekistan, 1,457 in Turkmenistan, 920 in Tajikistan.

There are approximately 300,000 M ha of agricultural land in Central Asia. The five countries have their own specialization in agricultural production. Thus, Uzbekistan has more irrigated land area compared to Turkmenistan. Kazakhstan has more rangelands than all the other republics together. The rangeland areas occupy about 82 % of the total area, followed by irrigation agriculture and dry-land agriculture, which occupy 7.2% 6.9% respectively. The forest/woodland areas occupy 4.2 % of the total area. Of the 8.6 M ha⁻¹ of irrigated lands in the region, more than half, i.e., 4.52 M ha, are situated in Uzbekistan.

The Central Asian countries face three major challenges: *ensuring food security, alleviating poverty, and protecting the environment* (Beniwal et al., 2000). The region faces a serious challenge to its natural resource base. Croplands, rangelands and mountains are becoming more degraded. The reduced availability of agricultural inputs and feed and fodder is resulting in a decline in livestock numbers. Water scarcity and misuse is compounding the threat to food security, human

health, and ecosystems. There are three types of agroecosystems in Central Asia, e.g., *irrigated croplands*, where the main crops are cotton, wheat, corn, forages, vegetables; *rainfed farming*, where forages and crops are dominant; and *rangelands*, where grazing, firewood collection, medicinal plants are the main activities.

SOILS

Soil is one of the most vital natural resources in any region, because, without it, agricultural activity is not possible. It is also relatively easily destroyed or degraded by the careless action of man. Basic factors controlling soil formation and its main characteristic, fertility, are *climate, parent materials, vegetation, slope, hydrology, microorganisms*, human activity and *time or age of the soil*. In Central Asia, a number of soil types stand out as exceptionally important with regard to either total area of occurrence or agricultural productivity.

In terms of the Great Soil Group classification, these types are *Sierozems*, including *Lithosols*, and sands (Minashina et al., 1968). Various natural factors have caused the formation of the following types of soils in the territory of Central Asia: *floodplain-alluvial, meadow-grey, sandy desert, takyr desert, grey-brown desert, irrigated grey, light-grey, typical grey, mountain-brown*. The dry climate is the cause of weakly manifested soil-forming processes in this territory. Since soil formation is slow, the time factor is a dominant influence.

Arid soils commonly possess weak texture, high salinity, and low humus content (Rozanov, 1968). All the aforesaid soil types are formed and developed over deep groundwater and belong to automorphous, or self-forming soil, whereas in conditions of excessive moisture - in valleys, floodplains and river deltas - hydromorphous soils develop, e.g., *meadow-alluvial, meadow-marshy, marshy-meadow* and others develop. Their formation is associated with the shallow groundwater that is capable of wetting the entire upper soil layer through capillary rise.

Thus, they secure the development of specific marsh and meadow vegetation, vertical and horizontal salt migration and such like. A higher moisture content in hydromorphous soils, as compared to desert ones, ensures a better development of the former and a higher productivity of vegetation. At the same time, slower salinisation rates of vegetation remnants promote the formation of a relatively thick humus horizon. Under certain geomorphologic conditions, for instance, on lands with outcropping groundwater and on low river terraces, hydromorphous soils intermingle with automorphous soils.

Under natural conditions, soils of the desert zone have low fertility. Depending on the moisture content, as well as accumulation and degradation of organic

matter, irrigated soils fall into the following main types: meadow-oasis and marshy-oasis soils of the desert zone and taky- oasis soils as well as meadow-oasis and marshy-oasis soils of the grey-earth belt, soils of the plains. Differences in rocks in the various deserts and heterogeneous agro-hydrological properties of desert soil types affect their water regime as well as distribution of soils and properties within individual soil types (Kovda, 1980).

IRRIGATED CROPLANDS

During the Soviet period, major efforts were focused on irrigation and development of extensive monoculture cotton plantation, especially in the southern desert biome and cereal cultivation in the semi-desert. Irrigation of the Golodnaja Steppe in Uzbekistan and construction of the Karakum Canal, crossing the entire territory of Turkmenistan, are among the most impressive projects in this area. Several types of soil changes related to agricultural land-use can be found in these regions.

Irrigation is the major factor of soil transformation in the oasis areas in Central Asia. Although oasis-irrigated agriculture was developed in this region centuries ago, extensive irrigation started only at the beginning of the 20th century. Chestnut and brown soils in the semi-deserts of the Pre-Caspian Lowland and Central Kazakhstan, as well as relatively fertile light *Sierozems* of Turanian piedmont deserts (previously occupied by extensive pastures with spots of small-size oases) have been converted into vast irrigated plantations, with cotton monoculture in the south and wheat in the north .

Many studies have shown that the carbonate profile of irrigated soils changes noticeably under irrigation (Zakirov, 1986). However, the effects of irrigation depend on natural soil properties. In the fertile depressions with Chernozem-like soils of the Pre-Caspian Lowland, irrigation causes a general decrease in total carbonate accumulation and replacement of segregated forms by eluviated ones. It was pointed by some authors that significant organic carbon loss only occurs during the first years of irrigation (Razikov, 1980). After 12-15 years, the organic carbon content reaches an equilibrium, similar to initial values before irrigation.

At the same time, the reserves of organic carbon in the irrigated Chernozems are less than those in the non-irrigated ones. In the *Sierozem* soils of the Turanian deserts, which initially had a relatively low content of organic carbon, irrigation and fertilization in the oases increased the amount of soil carbon. While non-irrigated desert soils have a maximum organic carbon content not exceeding 1.5 t ha^{-1} in the light *Sierozem*, irrigated cultivated soils derived from these generally contain at least $3\text{-}5 \text{ t C ha}^{-1}$, although these figures may vary depending on management system.

A number of studies during the last few decades have focussed on various aspects of desertification in Central Asia. The Institute of Deserts of the Turkmen Academy of Science carried out the most detailed and basic study on human impacts and desertification processes in Central Asia. Also, the Ecological Map of Northern Caspian Lowland and the Map of Ecological Conditions for Phyto-ame-
lioration of the Aral Sea Basin (Bahaiev et al., 1989; Bahiaeve, 1993) provide a wide range of information on land degradation processes and ecological conditions of this region.

Table 3. The humus content of irrigated, rainfed and virgin soils of Uzbekistan.

Soils	Depth	Irrigated	Rainfed	Virgin
	----cm----	----- % -----		
<i>Typical and dark Sierozem soils</i>				
Dark Sierozem	0-30	-	1.3-1.5	2.0-3.5
	30-60	-	1.0-1.2	-
Typical Sierozem	0-30	1.1-1.7	0.8-1.1	1.8-2.5
	30-60	0.6-0.9	0.5-0.7	-
Meadow	0-30	1.5-2.5	1.8-3.5	2.5-3.5
	30-60	0.1-1.8	1.2-2.0	-
<i>Light Sierozem soils</i>				
Light Sierozem	0-30	0.9-1,3	0.6-0,8	1.5-1.9
	30-60	0.6-1,0	0.4-0,6	-
Meadow	0-30	1.2-1,7	-	2.0-2.5
	30-60	0.9-1,2	-	-
<i>Desert soils</i>				
Takyr	0-30	0.8-1,0	-	0.5-0.6
	30-60	0.5-0,7	-	-
Meadow	0-30	0.9-1,2	-	1.5-2.0
Gray- brown	30-60	0.7-0.9	-	-
	0-30	0.4-0.6	-	0.3-0.5
Sandy	30-60	0.2-0.3	-	-

Reserves of organic carbon in the irrigated *Chernozems* are less than those in the non-irrigated ones. In the *Sierozem* soils of the Turanian deserts, which initially had a relatively low content of organic carbon, irrigation and fertilisation in the oases increased the amount of soil carbon. While non-irrigated desert soils have a maximum organic carbon content not exceeding 1.5 t ha^{-1} in the light *Sierozem*, irrigated cultivated soils derived from these generally contain at least $3\text{-}5 \text{ t C ha}^{-1}$, although these figures may vary depending on the management system.

Soil organic matter is a complex mixture of animal and plant residues, fresh and at all stages of decomposition, living and decaying microbial tissue, and heterotrophic biomass, and relatively resistant humic substances. It has a number of beneficial properties for soils, even at low concentrations. Organic matter is one of the most complex, dynamic and reactive soil component. It is well known that soil organic matter has a significant role both in agricultural production and in relation to the environment. Land-use practices that involve soil disturbance and removal of vegetation have been widely observed to cause losses of soil C to the atmosphere. These losses account for about one-third of the atmospheric CO_2 that has accumulated since pre-Industrial times, and they indicate widespread soil degradation. There is currently much interest in reducing these losses through land-use practices that increase the sequestration of C in soils.

These practices include greater cropping frequency (Bremer et al., 1994; Campbell et al., 1997) reduced tillage, fertilizer application, application of organic amendments such as manure (Campbell et al., 1988), and cropping to perennial legumes and grasses (Bremner et al., 1994). Accurate estimates of changes in soil organic C with land use practices under site-specific conditions is very important. At this, the level of soil organic matter and its humus content are very important indicators of soil fertility. *Sierozem* soils have comparatively low humus content as compared to the more fertile *Chernozem* soils (Orlov, 1989). This can be explained by several natural conditions and the ways in which they are utilized.

Cotton in monoculture contributed to a decrease in the amount of organic carbon in a 50 years (Table 4). The same trend, though less pronounced happened in the case of cotton in monoculture with fertilizers. Even crop rotation (3 years of alfalfa and 7 years of cotton) could not maintain soil organic carbon at the initial level. During the 50 years of cotton cultivation, it lost approximately 40% of natural reserves of soil organic carbon in *Sierozem* soils. Monoculture of cotton and a surplus of irrigation after applying excessively high rates of mineral fertilizers have gradually decreased organic matter in the soil (Sattarov et al., 2000).

Table 4. Long-term dynamics of soil organic carbon.

Treatment	Organic carbon		Cotton yield			
	1930	1976	1926-47	1948-63	1964-76	1981-84
	----- % -----		-----t ha ⁻¹ -----			
Cotton, monoculture, no fertilizers	0.82	0.54	1.73	1.34	1.36	1.76
Cotton, monoculture with fertilizers	0.86	0.67	3.59	3.66	3.31	2.99
Cotton, monoculture, manure	1.01	1.01	3.09	3.54	2.73	3.11
Crop rotation , fertilizers	0.77	0.42	4.32	3.88	3.19	3.19

The difference in soil organic matter reflect a process of de-humification. The area under perennial legumes for crop rotations have been reduced to a minimum. The results of long-term experiments indicate that under cotton monoculture production without applying fertilizers, the organic matter content decreased by 40%, while with systematic application of mineral fertilizers, the losses of organic matter were rather smaller. In the crop rotation treatment, the restoration of organic matter content in the soil under alfalfa up to its initial index has been observed within a few years. However, under cotton, the organic matter content continued to decrease. Consequently, some crop rotation practicies do not ensure the organic matter maintenance on a large scale.

In connection with this, along with introducing the crop rotation practicies, it is nessesary to apply organic amendments such as manures, plant residues, industrial and municipal wastes containing organic substances. Tables 5 and 6 show that humus of Serozem soils has more fulvic acid than humic acid as compared to higher fertile Chernozem or Chesnut soils. The carbon contents of these compounds, as well as carbon-to-nitrogen ratio, are also lower.

The amount of above-ground biomass of the Sierozem soils is significantly lower that the Chernozems or other fertile soils types. But below-ground biomass is not as low and in , in some cases are higher than Chesnut soils. So, we can see some features of serozem soils and their transformation of incorporated organic residues. The range of organic matter or humus contents (t ha⁻¹) vary with the type of Sierozem, e.g., sandy (26-31), light (40-62), typical (59-107), dark (158). They are similar to Brown Solonetz (36), but dissimilar to Chestnut (100) and Chernozem (800) soils.

Table 5. Elemental composition of humic acids and ratio extracted from Sierozems.

<u>Soils</u>	<u>Carbon</u>	<u>Hydrogen</u>	<u>Oxygen</u>	<u>Nitrogen</u>	<u>H/C</u>	<u>O/C</u>	<u>C/N</u>
	-----%-----						
Podzol	37.5	39.8	20.3	2.4	1.0	0.5	15.6
Brown forest	37.4	42.2	17.9	2.5	1.1	0.4	14.9
Grey forest	38.1	40.3	19.2	2.4	1.0	0.5	15.9
Chernozem	42.5	35.2	19.9	2.4	1.0	0.5	15.9
Chesnut	47.7	42.1	17.1	2.8	1.0	0.4	13.9
Sierozem	39.0	40.1	18.1	2.7	1.0	0.4	13.9

Source: Orlov(1984): Carbon= C; Hydrogen=H; Oxygen=O; Nitrogen=N.

Table 6. Element composition of fulvic acids extracted from Sierozems.

<u>Soils</u>	<u>Carbon</u>	<u>Hydrogen</u>	<u>Oxygen</u>	<u>Nitrogen</u>	<u>H/C</u>	<u>O/C</u>	<u>C/N</u>
	-----%-----						
Podzol	33.4	39.3	25.3	2.0	1.1	0.7	16.6
Brown forest	30.8	40.9	26.1	2.2	1.3	0.8	13.9
Chernozem	30.9	40.6	26.3	1.31	0.8	0.8	14.3
Brown	32.2	34.9	30.9	2.0	1.0	0.9	16.3
Sierozem	29.4	41.7	26.7	2.2	1.4	0.9	13.3

Source: Orlov(1984): Carbon= C; Hydrogen=H; Oxygen=O; Nitrogen=N.

Table 7. Plant biomass incorporated into Sierozem, Chernozem, and Chesnut soils.

<u>Soils</u>	<u>Above-ground</u>	<u>Root</u>	<u>Total</u>
	----- t ha ⁻¹ -----	-----	
Sierozem, Sandy	0.5	10.0	5.0
Sierozem, Light	1.0	15.0	16.0
Sierozem, Dark	4.5	30.0	34.5
Chesnut	5.2	13.0	8.2
Chernozem	7.0	25.0	32.0

Source: Rozanov (1967)

SOIL CARBON

Except for the large oases alongside the major river valleys, where intensive irrigated agriculture was dominant for millennia, the most important human influences on the desert and semi-deserts biomes have been those connected with grazing. The domesticated herds of MiddleAsia and Kazakhstan are generally dominated by sheep, but camels and goats are also kept. The effects of grazing by domestic animals on vegetation and soils are thought to be different from those of the wild herds that preceded them. Domesticated herds move slowly and do not stray great distances from watering places (Le Houerou, 1989). They have an intensive impact on the pasture around the watering places, while the areas further away remain almost undisturbed.

The result is concentric pattern around watering places, with increasingly degraded vegetation as one approaches the centre. Close to the waterhole itself, where the animals remain the longest, there is no vegetation at all, and the soil is over-fertilised by animal excrement. The negative effect of this over-fertilisation on plant growth remains noticeable for many years after watering places have been abandoned. There is too little precipitation for leaching to take place. Former watering places are recognisable from a great distance as *barchan* fields.

The destruction of plant cover in intensively grazed areas often leads to the formation of barchan dune fields and chains. In the desert zone, around such a *barchan* field, one can usually find some vegetation cover, composed by such species as *Aristida karelinii*, *A. pennata*, *Astragalus chivensis*, etc. (Rustamov, 1994), all of these being plants which the livestock will not eat. Continuing outward from the centre, there follows a ring with semi-shrubs, such as *Eremosparton flaccidum*, *Salsola richteri*, *Ammodendron coollyi*, *Haloxylon persicum* and *Calligonum* species, as well as herbs, although *Carex physodes* is still poorly represented (Rodin, 1994; Babaev, 1996).

The 'natural' vegetation cover typical for this zone may be found only at a distance of several kilometres from the water source. On loamy soil the weed *Peganum harmala* (*Zygophyllaceae*) is found, which can also be found around watering places of many rangelands. In semi-desert areas under grazing pressure by domesticated herds, the perennial grasses disappear from the vegetation cover, while the number of annuals and biennials, especially *Poa bulbosa* var. *vivipara*, increases.

In order to discover the most rational ways of using desert rangeland, a series of experiments was carried out in the late 80s - early 90s near the research station of Repetec on an experimental area in the south eastern part of the Karakumi Desert, with a herd of several hundred sheep, goats and camels (Nechaeva et al., 1971). The average was 0.7 sheep or goat or 0.3 camel per ha, the minimum

was 0.1 sheep per ha, and the maximum was twice the average density. Medium occupancy with a correct rotation of grazing seasons proved to give the best results in terms of promoting vegetation cover in particular, promotion of *Carex physodes* - the best forage plant (Nechaeva, 1984). Grazing can thus exert both positive and negative effects on total vegetation cover, and by implication soil organic carbon (which is derived from plant material).

Positive effects involve a slight loosening of the soil surface; facilitation of seed germination by plants and the pressing of seeds into the soil under foot, and fertilisation of the soil through excrement. These positive effects are noticeable only at an intermediate grazing intensity. In contrast, with overgrazing, the soil is loosened *too much* and is blown away to start forming *barchan* fields. With under-grazing, the loosening is too little and unwanted mosses take over the area. Similarly, the pressing of seeds under-foot to the optimal depth occurs only with a moderate numbers of animals per hectare of pasture. Grazing the same area twice in the spring has proven to be very damaging, especially when it is done every year, as it is often the case. The pastures become degraded after only 2 or 3 years. It was found that the arid pasture areas suffer less, when they are divided into many lots, each of which is grazed alternatively for a short period during each season (rotation grazing). This presupposes, however, that all the paddocks have similar plant covers, which is seldom the case.

With heterogeneous pastures, the rotation must be adapted to the particular local conditions. One must also consider the location of the watering places. One variation, that of alternative grazing of a paddock in the spring and summer one year and in autumn and winter the next year, proved to be also useful (Nechaeva, 1985). Under rotational use with moderate occupancy, optimal utilization could be sustained without damaging the plant and soil cover of the pastures. A short period of grazing during each season most closely resembles the original use by the wild herds, which never remained for very long in any one place. On the other hand, with the almost total extinction of natural ungulate fauna in this area (as occurred hundreds of years ago in this region), a complete protection of the grazing field would not have a positive effect on overall vegetation cover because annual grasses or moss gradually replace the sparser natural perennial vegetation, and the surface becomes more compacted.

So what then are the effects of the artificial grazing regime on soil carbon? The effects are complex, with the direction of influence varying from one place to another. Moderate and rationally managed grazing generally favours sequestration of organic carbon in soils, both directly (organic matter from excrement) and indirectly (preserving perennial grasses such as *Carex physodes*, with well-developed root systems and high underground biomass). In contrast, overgrazing is the main reason for losses of both vegetation and soil carbon and nitrogen in arid and semi-arid rangelands.

In general, there has probably been widespread loss of soil carbon from Central Asian desert ecosystems since the time of the domestication of ungulates, and especially the increase in herds over the last century. Apart from grazing, the impact of humans in the Central Asian desert environments has been relatively insignificant and is restricted to several urban and industrial sites (especially mining and oil-extraction regions) and large oases with irrigated agriculture alongside the major river valleys and artificial canals.

CONCLUSIONS

In general, the level and total amount of soil organic matter in different types of Sierozems of Central Asia and similar areas of the world are comparatively low. It can be explained by influence of dry climate, low precipitation during autumn-winter-spring time and higher temperatures during summer. Natural fertility of soils of desert zone is low, by comparison with soils of other ecosystems, e.g., 0.4-0.6%. But irrigation and cultivation can increase both the level and total amount of soil organic matter up to 1.2-2.0% depending on climax environmental conditions. Cotton monoculture for almost 30 years has caused a loss of approximately 35-40% soil organic matter reserves in all types of Sierozems. Rainfed wheat farming in virgin soils also contributed the same problem.

Due to frequent soil mechanical treatment, irrigation and high application rates of mineral fertilizers, mineralization of organic matter dominates over humification and accumulation. So it is very important to establish management strategies which could help to maintain the initial soil organic matter content and restore what has been lost.

On the basis of laboratory and field investigations, some agrotechnologies to reproduce soil fertility were developed: *organic farming* (application of farmyard manure, green manuring), *deep ploughing* and *incorporation of organic residues*, *zero* or *minimum*, *tillage*, application of organic fertilizers combined with cultivation of perennial crops, especially under legumes, and application of composts derived from different agro-industrial and urban wastes.

All these technologies have their positive and negative aspects. For example, deep ploughing or application of composts takes a lot of time, space and resources. The sources of organic fertilizers are too scarce for the large area of irrigated farming. The most acceptable approach is application of any available organic materials suitable for application as fertilizers under cultivation of legumes. Reduced or zero tillage and slow mineralization due to anaerobic conditions can create optimal conditions for transformation of incorporated organic matter into stable soil organic matter.

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Daily and Growing Season Fluxes of Carbon Dioxide in Rangelands of Central Asia

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ABSTRACT

Global climate change is expected to alter the distribution of sources and sinks for atmospheric carbon dioxide (CO₂) and increase uncertainties in the global carbon cycle. Recent estimates of global carbon budget indicate the existence of a 'missing sink' for atmospheric CO₂, and we hypothesize that the vast rangeland areas of the world could be a part of this 'missing sink'. The main objective of this study was to document the daily magnitudes and dynamics of CO₂ fluxes in rangelands of Central Asia throughout the growing season.

We used the Bowen ratio-energy balance technique for continuous measurements of net ecosystem CO₂ exchange (NEE) between the atmosphere and rangeland ecosystems at three study sites: 1) True grassland steppe in Shortandy, Kazakhstan; 2) Sagebrush-ephemeroid semidesert in Karnap, Uzbekistan; and 3) Shrub sandy desert in Karrykul, Turkmenistan. We obtained NEE and associated micrometeorological measurements at 20-minute averaging intervals for growing seasons of three years (1998-2000).

Total growing season NEE ($\pm$ SE, n=3 years) during measurement periods (111 to 173 days) indicated that Central Asian rangelands were sinks for atmospheric CO₂ in the order: 659 $\pm$ 67 at Shortandy > 347 $\pm$ 178 at Karnap

> 151 ± 121 g CO₂ m⁻² season⁻¹ at Karrykul. Historical climatic data (1961-93) from weather stations near the study sites had annual precipitation as 324 at Shortandy, > 237 at Karnap, and > 113 mm yr⁻¹ at Karrykul. As expected, precipitation was a key factor in determining the CO₂ sink capacity of Central Asian rangelands during the growing season. Measurements are ongoing at each study site to quantify CO₂ fluxes for the non-growing season (fall-winter-snowmelt period) to allow estimation of annual carbon balance.

INTRODUCTION

The global climate is changing due to increasing atmospheric concentrations of greenhouse gases, e.g., carbon dioxide CO₂, methane CH₄, and nitrous oxide N₂O and aerosols (microscopic airborne particles or droplets, that act as radiative forcing agents causing global temperature to rise. The Intergovernmental Panel on Climate Change (IPCC) reported that the atmospheric concentration of CO₂ has increased by 31% since 1750, and the rate of increase in atmospheric CO₂ has been about 1.5 μL L⁻¹ yr⁻¹ (0.4%) during the past two decades. During the 1990s, the year-to-year increase varied from 0.9 μL L⁻¹ (0.2%) to 2.8 μL L⁻¹ (0.8%) as influenced by climatic variability (e.g., El Niño events). This rate of increase is unprecedented during at least the past 20,000 years (IPCC, 2001a).

An option to mitigate the effects of global climate change is through terrestrial ecosystem and land management. Mitigation is defined as human intervention to reduce the sources of greenhouse gases or enhance their sinks. An ecosystem depleted of carbon by past events may have high potential rate for carbon accumulation, while one with a large carbon pool would tend to have a low rate of carbon sequestration. Thus, management strategies for an ecosystem may depend on whether the goal is to enhance short-term accumulation or to maintain carbon reservoirs through time (IPCC, 2001b).

The magnitude of reservoirs and annual fluxes for various components of the global carbon cycle are depicted in Fig. 1. Recent estimates indicate large uncertainties in the global carbon budget. For example, the National Aeronautics and Space Administration (NASA) reported a 'missing sink' for atmospheric CO₂ that is equivalent to 1.9 GtC yr⁻¹ (Fig. 1; see NASA, 2001). Evidence points to the land surface as the 'missing sink', but it is not certain which processes dominate, or in what regions of the Earth this missing carbon flux occurs.

Various landscapes have been hypothesized as potential contributors to the 'missing sink' such as ecosystems of the contiguous United States (Schimel et al., 2000) and boreal and northern temperate forests (Herring and Kannenberg, 2001; Myneni et al., 2001). A global network of eddy flux micrometeorological stations,

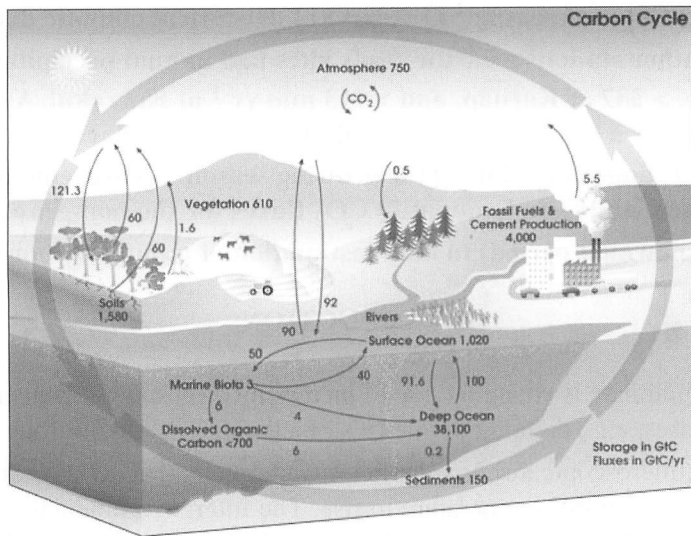


Fig. 1. In any given year, tens of billions of tons of carbon move between the atmosphere, hydrosphere, and geosphere. Total anthropogenic CO_2 source is 7.1 GtC yr^{-1} (5.5 for burning of fossil fuels plus 1.6 for deforestation) and total sink is 5.2 GtCyr^{-1} (3.2 for atmosphere plus 2.0 for oceans). Thus, there is a 'missing sink' for atmospheric CO_2 of about 1.9 GtC yr^{-1} . This illustration shows carbon reservoirs in dark text, and annual carbon fluxes in light text. Adopted from NASA (2001).

FLUXNET, has found that rates of net carbon uptake by tropical and temperate forests were substantial and exceeded estimates previously generated with biospheric modeling systems (Baldocchi et al., 2001). Scientific interests concerning global climate change also led to the formation of USDA-ARS Rangeland Carbon Dioxide Flux Project to determine the role rangelands in the global carbon cycle and assess the net primary production among various rangeland ecosystems in the western United States (Svejcar et al., 1997). Furthermore, vast areas of grazing lands - a collective term that includes all lands having vegetation harvested by grazing without reference to land tenure or other land uses, management, or treatment practices - are believed to have a large potential to sequester carbon and mitigate the greenhouse effect in the United States (Follett et al., 2001). Although arid and semi-arid ecosystems are known to have substantially lower productivity than forests, we hypothesize that the vast landscapes of Central Asia dominated by rangeland ecosystems could be an important contributor to the 'missing sink'. Thus, the main objective of this study was to document the daily magnitudes and growing season dynamics of net ecosystem CO_2 exchange (NEE) in representative rangelands of Kazakhstan, Uzbekistan, and Turkmenistan.

MATERIALS AND METHODS

Study Sites

Field stations for the measurement of CO₂ and water vapor fluxes, energy balance, and associated micro-meteorological characteristics were established at the beginning of the growing season in 1998 at three sites, which characterized representative rangelands of Central Asia. These sites were: A) *True steppe* at Shortandy, Kazakhstan; B) *Sagebrush-ephemeroid* semi-desert at Karnap, Uzbekistan; and C) *Shrub sandy desert* at Karrykul, Turkmenistan. Location of the sites and the areas of rangeland types they represent are described in Fig. 2.

True Steppe at Shortandy, Kazakhstan.

The true steppe at Shortandy site is representative of the vast **grassland** area spreading from the lowlands of the northern Black Sea through southern parts of the Russian Plain to the steppes of northern Kazakhstan. This site was located at 51°40' N, 71°00'E, 367 m a.s.l., on the field experimental station of the Kazakh Research Institute of Grain Farming, near the town of Shortandy, about 60 km NNE of Astana. The average annual air temperature at this site is 1.1°C, and precipitation is 324 mm. Climate at Shortandy is characterized by a summer maximum of precipitation with generally favorable growth conditions during the growing season. Precipitation is characterized by high yearly variability with up to 50% of the years exhibiting drought in June and sometimes in July. The vegetation at the Shortandy site is classified as a semiarid grass-forb steppe dominated by *Stipa capillata*, *Stipa lessingiana*, *Agropyron cristatum*, *Kochia prostrata*, *Medicago falcata*, *Festuca valesiaca*, *Salvia stepposa*, *Artemisia marshalliana*, and *Artemisia glauca*. The soil at the site is a southern chernozem with a soil organic carbon reserve of 18.8 kg C m⁻² (Titlyanova, 1988).

Sagebrush-Ephemeroid Semi-desert at Karnap, Uzbekistan

The Karnap site represents the sagebrush-ephemeroid arid rangelands of the foothills of Central Asia and was located on the territory of the agricultural enterprise "Razzok Jahangirov", 150 km NWW from Samarkand (40°N, 65°30'E, 310 m a.s.l.). Macroclimate of the sagebrush-ephemeroidal semi-desert at Karnap is characterized by an annual air temperature of 14.6°C and precipitation of 237 mm. The annual distribution of precipitation at the Karnap site is characterized by a maximum of precipitation in winter-spring followed by a typical drought during June-October. The dominant shrub species at the Karnap site are sagebrush (*Artemisia diffusa*) and yantak (*Alhagy pseudoalhagy*), while the grass layer is dominated by *Poa bulbosa*. The soil is classified as loamy serozem with an occasional gypsum horizon in the soil profile.

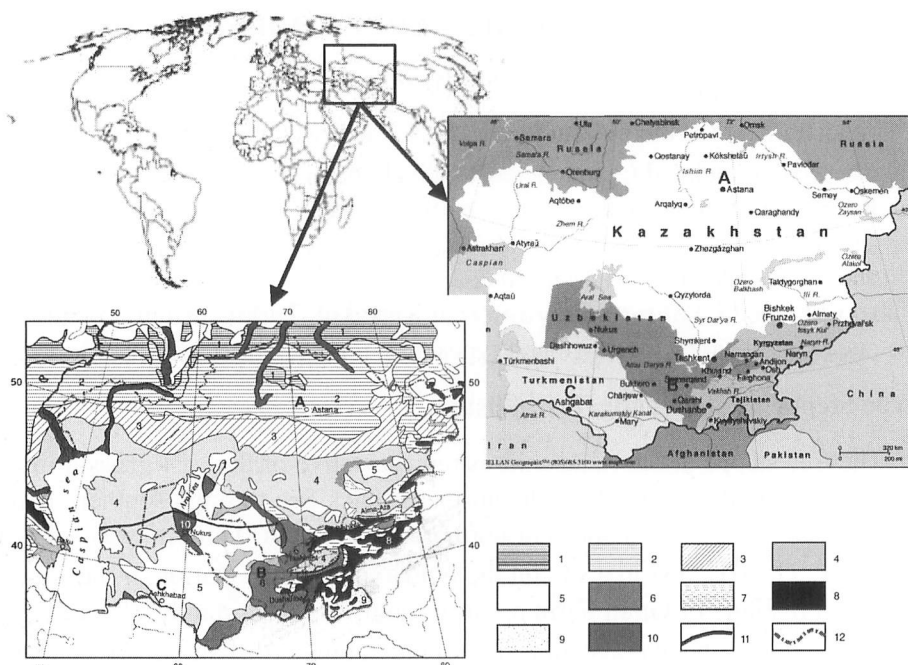


Fig. 2. Top: world map depicting the region of Central Asia. Middle: political map of Central Asia with the three CO₂ flux study sites identified as A, B, and C. Bottom: schematic map of major natural zones of Central Asia: 1 - meadow steppe; 2 - true steppe; 3 - dry (desertified) steppe; 4 - sagebrush-saltwort-ephemeroidal desert (mostly northern); 5 - shrub desert (often sandy) (mostly southern); 6 - ephemeroidal foothill semidesert/desert; 7 - mountain steppe; 8 - alpine/subalpine meadow and mountain forest; 9 - high mountain semidesert/desert; and 10 - alluvial ecosystem. Also, included on the map is a solid dark line, which depicts the general border between "northern" and "southern" deserts, and a dashed line, which depicts country boundaries. The CO₂ flux study sites are indicated as A - true steppe at Shortandy, Kazakhstan; B - foothill semidesert at Karnap, Uzbekistan; and C - shrub sandy desert at Karrykul, Turkmenistan.

Shrub Sandy Desert at Karrykul, Turkmenistan

The shrub sandy desert at the Karrykul site represents the majority of the rangelands of Turkmenistan (26 million ha). This site was located at the Karrykul Research Station of the National Institute of Deserts, Flora and Fauna of the Ministry of Nature of Turkmenistan in the southern part of the Central Karakum Desert, 80 km to the north of Ashkhabad (38°36'N, 58°24'E, 90 m a.s.l.). The annual air temperature at the Karrykul site is 15.6°C, and precipitation is 113 mm. Most of the precipitation occurs during the winter and spring (88 mm), while mid-May to mid-October is characterized by severe drought (25 mm). The principal landscape elements of the Central Karakum Desert include: (1) high sand

ridges covered with a *Calligonum rubens* - *Mausolea eriocarpa* - *Carex physodes* community, (2) plain hillocky areas between the ridges with a *Calligonum setosum* - *Salsola arbuscula* - *Artemisia kemrudica* - *Carex physodes* community on stabilized sands with desert sandy soils, and (3) local flat depressions ('takyr') with a *Salsola gemmascens* - *Artemisia kemrudica*-*Gamanthus gamocarpus* community on clay (and often salinized) takyr soils.

Bowen Ratio-Energy Balance Measurements

Continuous measurements of CO₂ fluxes at the three study sites were obtained with Bowen Ratio-Energy Balance (BREB) systems during the growing seasons of 1998-2000. The theory and operation of the BREB system (Model 023/CO₂ Bowen Ratio, Campbell Scientific Inc. (CSI), Logan, Utah) were described in detail by Dugas (1993) and CSI (1998). Briefly, CO₂ and water vapor concentrations were measured with an infra-red gas analyzer (IRGA; Model LI-6262, Li-Cor Inc., Lincoln, Nebraska) in the differential mode. Air samples above the surface of vegetation from two heights were drawn and routed to the IRGA, which measured the concentration gradients at a 1-m distance between the two heights.

A low-power pump (Model TD-3LSC, Brailsford and Co., Inc., Rye, New York) aspirated the air through 1- μ m teflon filters (Model Acro 50, Gelman Sciences, Ann Arbor, Michigan), which prevented dust and liquid water contamination in the air tubes and IRGA. A solenoid valve (Model 236-102B, Numatics Inc., Highland, Michigan) was programmed to reverse the air drawn through the IRGA every two minutes. Another solenoid valve was programmed to control the air stream at the beginning of each hour; thus, the IRGA sample cell was scrubbed to determine absolute concentrations of CO₂ and water vapor. The air temperature gradients at the two heights were simultaneously measured with fine-wire, chromel-constantan thermocouples. The CO₂, water vapor, and temperature gradients were measured every second, and the average gradients were calculated and stored every 20 min with a datalogger (Model CR23X, Campbell Scientific Inc.).

Fluxes of CO₂, water vapor, and energy were calculated using the 20-min averages. Bowen ratios were calculated from temperature and water vapor gradients. Soil heat flux at the ground surface was calculated with measurements obtained from soil heat flux plates (Model HFT3, REBS), and soil temperature probes (Model TCAV, Campbell Scientific Inc.) positioned above the soil heat flux plates. Sensible heat flux was calculated from the Bowen ratio, net radiation (Model Q*7.1 net radiometer, REBS, Seattle, Washington), and soil heat flux. The eddy diffusivity, which was assumed equal for heat, water vapor, and CO₂, was calculated from sensible heat flux and temperature gradients.

The eddy diffusivity may not be valid when the direction of sensible/latent heat flux is opposite the sign of temperature/water vapor gradient, or when the Bowen ratio approaches -1.0 (Ohmura, 1982). Under such conditions, the eddy diffusivity was calculated using wind speed, atmospheric stability, and canopy height (Dugas et al., 1999). This alternate method for calculating eddy diffusivity was applied at sunset, sunrise, and sometimes at night when fluxes and gradients were small; these instances occurred for about 14% of the 20-min measurements.

The CO₂ flux was calculated as the product of the eddy diffusivity and CO₂ gradient, and corrected for vapor density gradients at the two heights (Webb et al., 1980). Fine-wire thermocouple measurements indicated that temperatures were the same for the air entering the sample and reference chambers of the infrared gas analyzer so corrections for temperature differences were not applied (Angell et al., 2001). For time periods when technical difficulties resulted in no data for gradients of CO₂ and water vapor, fluxes at 20-min and daily temporal scales were estimated using semi-empirical models developed for each study site as described by Gilmanov et al. (2003).

RESULTS

Net Ecosystem CO₂ Exchange

Values of net ecosystem CO₂ exchange (NEE; mg CO₂ m⁻² s⁻¹) calculated from 20-min averaging intervals (n=72 per 24-h period) are presented in Fig. 3 for sunny days in 1999 that represent peak seasonal growth for each study site. Positive values of NEE indicate CO₂ uptake by the ecosystem via photosynthesis during the day (e.g., white symbols in Fig. 3), whereas negative NEE values denote CO₂ efflux from the ecosystem (e.g., black symbols in Fig. 3). All three sites had similar patterns of NEE during their respective 24-h period at peak season, with negative values at night gradually becoming positive after sunrise, reaching peak values near mid-day, declining in the afternoon, returning to negative values before sunset, and remaining near zero or negative throughout the night.

The range of NEE values for the three sites were: A) -0.13 to 0.55 mg CO₂ m⁻² s⁻¹ for the *true steppe* at Shortandy, Kazakhstan; B) -0.07 to 0.56 mg CO₂ m⁻² s⁻¹ for the *sagebrush-ephemeroid* semidesert at Karnap, Uzbekistan; and C) -0.01 to 0.46 mg CO₂ m⁻² s⁻¹ for the *shrub sandy desert* at Karrykul, Turkmenistan. The day of year (DOY) representing peak seasonal growth was in the order: 184 at Shortandy > 128 at Karnap > 85 at Karrykul. These represent differences in the timing of maximum growth with peak season at Karnap

occurring 56 before that at Shortandy, peak season at Karrykul occurring at 43 days before that at Karnap, and peak season at Karrykul occurring 99 days before that at Shortandy.

Separating the NEE values into day, i.e., (photosynthetically active radiation (PAR) > 0; data not shown) and night (PAR = 0) periods, and integrating the 20-min NEE values for each day/night period allowed the partitioning of daily (24-h) integrated NEE into daytime (NEE_{day}) and night-time (NEE_{night}) flux integrals. Thus, the sum of NEE_{day} and NEE_{night} for each 24-h period represents the daily NEE. Consistent patterns were found in NEE ($g\ CO_2\ m^{-2}\ d^{-1}$) characteristics according to ecosystems or study sites (Fig. 3):

NEE_{day} :	16.9 at Shortandy > 12.7 at Karnap > 4.7 at Karrykul
NEE_{night} :	-1.4 at Shortandy < -1.0 at Karnap < -0.1 at Karrykul
Daily NEE:	15.5 at Shortandy > 11.7 at Karnap > 4.6 at Karrykul.

Thus, the magnitude of daily NEE at the peak of growing season was highest in the true steppe at Shortandy, intermediate in the sagebrush-ephemeroid semidesert at Karnap, and lowest in the shrub sandy desert at Karrykul.

Seasonal Dynamics of Daily Net Ecosystem Exchange

Variations in daily NEE during the 1998-2000 growing seasons are shown in Fig. 4. Mean maximum daily NEE values ($\pm SE$, $n=3$) had the ranking: 11.0 ± 4.0 at Shortandy > 6.5 ± 3.4 at Karnap > $4.2 \pm 1.0\ g\ CO_2\ m^{-2}\ d^{-1}$ at Karrykul. The relatively large standard errors of the mean were indicative of the inter-seasonal variations in the timing of various micro-climatic events such as onset of snowmelt, amount and frequency of rainfall, and cloudiness. For example, mid-season declines in Figs. 4A and B were associated with days of rainfall and accompanying reduced PAR that resulted in decreased photosynthesis and increased soil CO_2 effluxes.

The shrub sandy desert at Karrykul had the longest growing season at 173 days, followed by 136 days for the true steppe at Shortandy, while the sagebrush-ephemeroid semidesert at Karnap had the shortest growing season with 111 days (Fig. 4). The sum of daily NEE across the number of days at each site provided an estimate of the cumulative NEE for the growing season: 659 ± 67 at Shortandy > 347 ± 178 at Karnap > $151 \pm 121\ g\ CO_2\ m^{-2}$ at Karrykul.

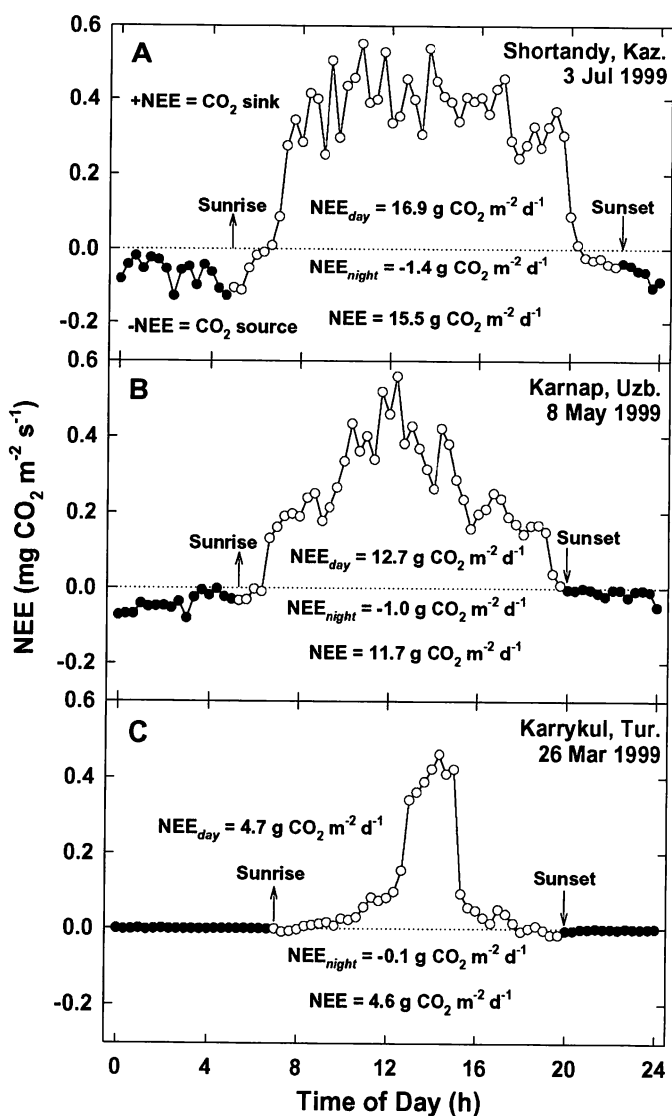


Fig. 3. Time course of net ecosystem CO₂ exchange (NEE, mg CO₂ m⁻² s⁻¹) at 20-min averaging intervals on sunny days at peak vegetative growth in 1999 for three study sites in Central Asia: A) true steppe at Shortandy, Kazakhstan on 3 July (Day of Year (DOY) = 184); B) sagebrush-ephemeroïd semidesert at Karnap, Uzbekistan on 8 May (DOY = 128); and C) shrub sandy desert at Karrykul, Turkmenistan on 26 March (DOY = 85).

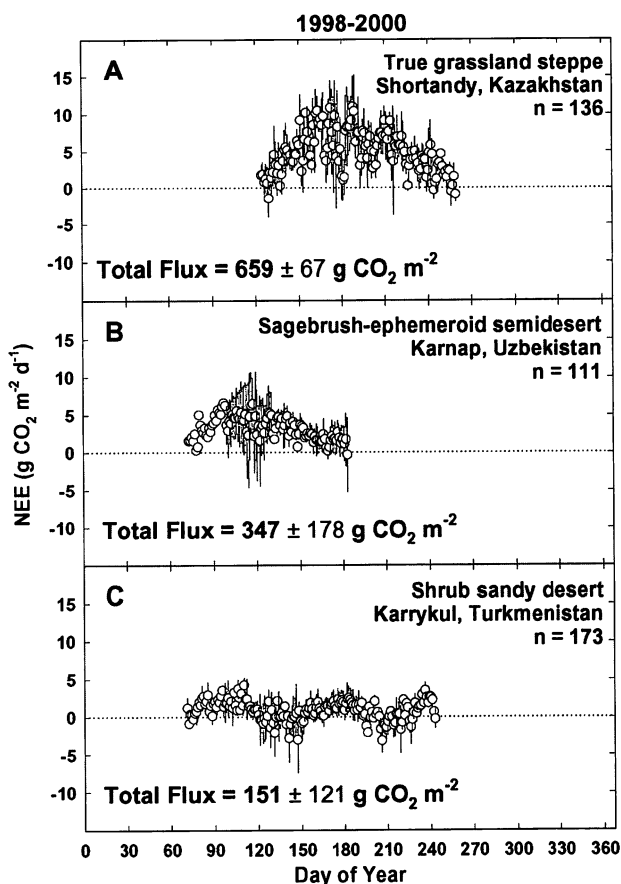


Fig. 4. Time course of daily net ecosystem CO_2 exchange (NEE , $\text{g CO}_2 \text{ m}^{-2} \text{ d}^{-1}$) during the growing seasons of 1998-2000 for three study sites in Central Asia: A) true grassland steppe at Shortandy, Kazakhstan ($n=136$ days); B) sagebrush-ephemeroid semidesert at Karnap, Uzbekistan ($n=111$ days); and C) shrub sandy desert at Karrykul, Turkmenistan ($n=173$ days). Total flux ($\pm\text{SE}$, $n=3$ years) for the growing season is listed for each site. Data points ($\pm\text{SE}$, $n=3$ days) represent mean daily NEE for each day of year.

DISCUSSION

Results from our 1998-2000 measurements of daily and growing season NEE indicated that rangelands of Central Asia are potential sinks for atmospheric CO_2 . Among the three study sites, differences in magnitude of 20-min and daily NEE at peak season (Fig. 3) were consistent with the variations in CO_2 sink capacity for

the whole growing season (Fig. 4). Long-term precipitation data (1961-93 from nearby weather stations) indicated that mean annual precipitation was in the order: 324 at Shortandy > 237 at Karnap > 113 mm yr⁻¹ at Karrykul. This trend of annual precipitation agreed with the pattern of total NEE for the growing season that we found among the three rangeland sites in 1998-2000 (Fig. 4). This suggests that annual precipitation is a key environmental factor influencing the capacity of Central Asian rangelands as sinks for atmospheric CO₂.

When we compare our results with growing season NEE obtained from various rangelands in previous studies (Table 1), the growing season NEE for our three study sites in Central Asia were within the range of values reported for rangeland ecosystems in the western United States. It is necessary, however, to obtain the annual carbon balance to improve the assessment of the role of rangelands in the global carbon cycle. Thus, we have ongoing efforts to measure and quantify the non-growing season (fall-winter-snowmelt period) NEE at our study sites in Central Asia.

Table 1. Total net ecosystem carbon dioxide exchange for the growing season in various rangeland ecosystems.

Rangeland Ecosystem	Growing Season NEE	Reference
	g CO ₂ m ⁻² season ⁻¹	
Mixed-grass prairie, Wyoming	243 to 334	LeCain et al., 2000
Mixed-grass prairie, North Dakota	287 to 538	Frank et al., 2000
Sagebrush steppe, Idaho	284 to 1103	Gilmanov et al., 2003
Southern mixed prairie, Oklahoma	49 to 731	Sims and Bradford, 2001
Tallgrass prairie, Kansas	750	Kim et al., 1992
Tallgrass prairie, Texas	850 to 1220	Dugas et al., 1999
Shrub sandy desert, Turkmenistan	151 ± 121	Present study
Sagebrush-ephemeroid semidesert, Uzbekistan	347 ± 178	Present study
True grassland steppe, Kazakhstan	659 ± 67	Present study

In conclusion, our results are instructive because they serve as useful baseline information in formulating strategies for the management of rangelands as a key option for mitigating global climate change. This is particularly important for the region of Central Asia where rangeland ecosystems are the predominant landscape. In the present study, we used relatively pristine ecosystems typical of the landscape at each locality, and found that all three rangeland sites were net sinks for atmospheric CO₂ during the growing season. This suggests that rangelands, which have been degraded through overgrazing and mismanagement, may provide stronger CO₂ sink capacities than pristine rangelands, possibly on a short-term basis.

Proper management and revegetation of degraded rangelands in Central Asia should lead to increased sequestration of carbon in soils, thereby increasing soil organic matter content, which is a key ingredient for more productive rangelands and sustainable agricultural ecosystems. Finally, when considered as a resource or commodity, soil carbon could be a good source of income for small farmers if soil carbon accounting and management system for emissions trading are developed and implemented (SM CRSP, 2002).

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Agriculture and Rangelands in Middle Asian Countries

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ABSTRACT

Middle Asia (often mistakenly called "Central Asia") covers the territory of the five new republics, i.e., Turkmenistan, Uzbekistan, Kazakhstan, Tajikistan and Kyrgyzstan. This region is submitted to a cold to very cold winter Mediterranean climatic conditions with dominant winter-spring precipitation and very hot summers. Rangelands occupy of major part of the whole region, but are a neglected sector despite being of immense value economically and ecologically. This paper presents the ecology and vegetation types of the region and reviews and comparing the trends in agriculture and rangeland between the different countries during the post-Soviet Era 1992-2002. Special emphasis is given to the extent of rangeland degradation and strategies for dealing with it.

INTRODUCTION

The five new republics of Middle Asia are located in the same latitude range (35-46°) as the steppe land of northern Syria - Turkey, Jordan, Iraq-Iran, Spain, the Maghreb in the old Mediterranean World, the Chinese Taklamakan, Gobi and Inner Mongolia to the East, the US Great Basin (California, Oregon, Idaho, Washington, Nevada, West Utah) in the North American continent, and Patagonia (Argentina) in the Southern hemisphere.

Most of the Middle Asian region is subjected to a very cold variant of Mediterranean semi-arid and arid climatic conditions, i.e., low precipitation as rain and snow during the cold winter-spring, with extreme minima often falling below -20°C. The agricultural land and crop yield are limited because of climate, poor soils, and land aridity limitations.

The largest country of Middle Asia is Kazakhstan (272.5 million hectares), with: 16.1 million people, followed by Turkmenistan (48.8 Mha, 4.8 M), Uzbekistan (44.7 M ha, 25.2 M), Kyrgyzstan (19.3 M ha, 4.9 M)) and Tajikistan

(14.3 Mha, 6.1 M), with a percentage of agricultural area (FAOSTAT, 2002) of 76, 66, 62, 54 and 32 %, respectively. In terms of area (Table 1), Kazakhstan has still the largest area of arable land under temporary crops (mostly rainfed cereals, with 13.9 Mha harvested in 2002) followed by Uzbekistan (1.7 M ha cereals).

Table 1. Agricultural area, arable land, permanent crops, permanent pastures in the five republics of Middle Asia (FAOSTAT, 2002).

Land details	Kyrgyzstan		Kazakhstan		Tajikistan		Turkmenistan		Uzbekistan	
Agricultural Area	10, 758	% ¹	206, 769	% ¹	4, 560	% ¹	32, 515	% ¹	27, 630	% ¹
Arable Land (Under temporary crops, cereals, etc)	1, 400	13,01	21, 535	10,4	930	20,4	1, 750	5,4	4, 485	16,2
Permanent Crops (Fruit trees, vines, etc.)	67	0,62	136	0,1	130	2,9	65	0,2	345	1,2
Permanent Pasture (Rangelands)	9, 291	86,36	185, 098	89,5	3, 500	76,8	30, 700	94,4	22, 800	82,5

¹ Percentage of agricultural area

Uzbekistan has the largest area of permanent crops (fruits trees, vines, etc.), with some 0.345 M ha from the best agricultural hilly and well-watered areas of the country. Irrigation plays an important role in all the five countries where nearly all arable land and permanent crops (99%) are irrigated in Turkmenistan (Table 2), a large part (88%) in Uzbekistan, about 70 % in Kyrgyzstan and Tajikistan and only around 11% in Kazakhstan reflecting the gigantic importance of rainfed cereal cropping in this last country. Most of the areas are covered with lowland rangelands as poor soils and water availability restrict even extensive cropping.

Kazakhstan has the largest area of rangelands (185 M ha; 89 % of agricultural area) mostly steppe and large tracks of sandy desert, followed by Turkmenistan (30.7 M ha; 94.4 %) mainly of the Karakum sandy desert, Uzbekistan (22.8 Mha, 82.5 %) covered by steppe land and sandy desert of the Kyzylkum desert. Kyrgyzstan and Tajikistan have essentially mountainous rangelands and highland forests that cover 9.3 (86.3 %) and 3.5 (76.8%) M ha of each country, respectively.

Local tradition have learned to make the best use of immense tracks of steppe and desert rangelands by developing appropriate extensive nomadic and semi-nomadic livestock production systems. These Middle Asian rangelands play an essential role for the local agriculture and economy. They cover the lowlands and mid-altitude regions of Turkmenistan, Uzbekistan, South-western Kazakhstan, Kyrgyzstan, and Tajikistan, i.e., some 65 % of a total of 400 M ha of these five countries. This corresponds with Eig's definition (Eig, 1931; 1932) of the Eastern

Mediterranean Steppe Zone or the Irano-Turanian phyto-geographic Province. These areas are also phyto-geographically known as "Middle Asia" (Lavrenko,1950).

Table 2. Contribution of irrigation to arable land and permanent crops in the five republics of Middle Asia from (FAOSTAT, 2002).

	Kyrgyzstan	Kazakhstan	Tajikistan	Turkmenistan	Uzbekistan
Arable/ Permanent Crops (10 ³ ha)	1, 467	21, 671	1, 060	1, 815	4, 830
Irrigated (10 ³ ha)	1, 072	2, 350	719	1, 800	4, 281
%	73.1	10.8	67.8	99.2	88.6

CLIMATE

The Middle Asian rangelands are subjected to a cold to very cold winters and Mediterranean climatic conditions with most of annual precipitation occurring as snow and rain during the cold season (winter, spring and autumn); summers are always dry and hot (Fig.1). This indicates a similarity to the Mediterranean climate (Walter and Leith, 1960; Walter and Box 1983, Le Hou  rou, **in press**). However, the Mediterranean Basin climate has, generally speaking, mild winter temperatures compared with those encountered in Uzbekistan. Most of these Middle Asian ranges receive exclusively winter-spring precipitation, in contrast with "Central Asia" covering Northwest China and Mongolia receiving mono-modal summer precipitation. The best example is Uzbekistan, which is also subject to the cold influence of the Arctic and Siberian fronts. These may reach the southern border near Afghanistan.

This characterizes the Middle Asian rangeland climate, which is predominantly *continental and sub-desertic*. The mean annual precipitation received as snow and rain on the lowland is about 100 mm in the Kyzylkum Desert and north of the Karakum Desert and the Amu-Darya River around the Aral Sea. It increases to 200-300 mm between the Kyzylkum Desert and west of a line Karshi-Navoi-Nuratau in Uzbekistan. It reaches over 600-700 mm in the eastern mountains, where they rise to over 3000 m. The ombrothermal graphs for Samarkand in Uzbekistan (Fig. 1) display a mono-modal curve with a strong peak in spring, unlike those of the North African littoral which display bimodal curves with a strong autumnal peak, and often a smaller one in spring). They are close to the mono-modal West Asian curves (Syria, Turkey, Jordan, Iraq, etc.) with a unique dominant precipitation peak during the winter coldest trimester and a smaller one in spring that may not appear; the appearance or not of this spring precipitation makes the difference between a *good year* and a *poor season* as a whole.

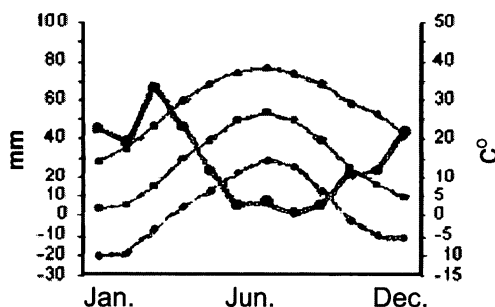


Fig. 1. Ombrothermal diagram for Samarkand (Uzbekistan); ▲ = Mean daily maximum (°C), ■ = Mean daily temperature (°C), ◆ = Mean daily minimum (°C), • = Mean Precipitation (mm)

Inter-Annual Variability

Precipitation conditions range productivity. The more the mean annual precipitation (MAP) is variable within years and between years; the more the range productivity is variable, thus rendering range management risky and difficult. This inter-annual variability, expressed by the MAP coefficient of variation is quite important in arid and semi-arid zones. In Uzbekistan for example, the MAP coefficients of variation for the period 1980-89, range between 27% and 34% in the low precipitation zone. It barely reaches 30% at the desert stations in the Kyzylkum, which receive around 100 mm MAP. It attains about 15-20% for the 200-600 mm MAP zone and 10% in the high rainfall regions receiving above 600 mm MAP.

Meteorological normals over 30-year period are not substantially different from these 10 year means. However, these MAP coefficients of variation appear to be far lower than those observed in arid zones of other Mediterranean areas (Le Houérou et al., 1993) where the MAP coefficient of variation reaches 25-45% in the 200-600 mm MAP zone, and 50-70% below 200 mm in North Africa, a region with mild to temperate winters.

This may also explain the greater stability of the rangeland production systems of Uzbekistan and possibly Middle Asia compared to other Mediterranean areas of the world. Year-to-year MAP variation determine the inter-annual stability of ecosystem production and livestock productivity on the range. When the MAP coefficient of variation is low, plant production is rather stable year after year, so is rangeland and livestock production when all other factors remain constant.

The correlation (Fig. 2) between MAP and coefficient of variation in Uzbekistan is poor due to a high dispersion of points and some incomplete data over a too short a period. But the variabilities in 80-100 years series of climatological data remain very low by Mediterranean standards. Further studies are required and may need some clarification and confirmation by extending the climatic period and zones studied (Le Houérou, *in press*). Similar MAP and low MAP coefficient of variation are observed in southern Kazakhstan (Ellis and Lee, 2002).

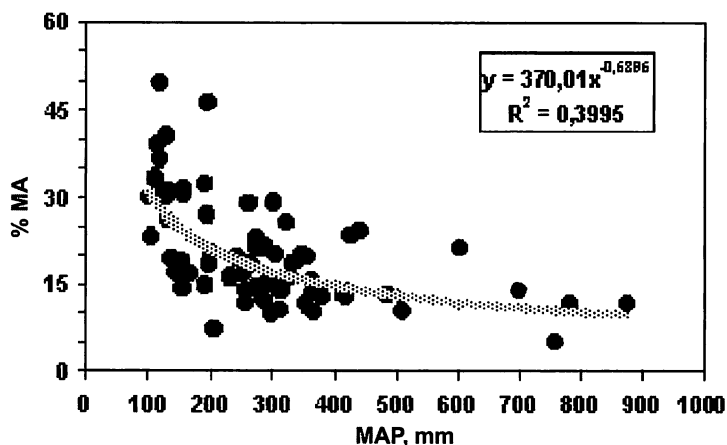


Fig. 2. Coefficient of variation of mean annual precipitation (Uzbekistan).

GEOLOGY AND GEOMORPHOLOGY

Uzbekistan is a good example of the regional geology and geomorphology. The central Turanian plain and the Turan region is a patchwork of gently undulating landscape intersected by folded sedimentary escarpments often with a metamorphic (gneissic) core or outcrop. This central plain covers about 60% of Uzbekistan. It is drained by the Amu-Darya and the Syr-Darya rivers into the Aral Sea, a depression some 60-100 m below sea level. It is largely open to the north, west and south, stretching from the western Ustyurt plateau to the emergent central Nuratau mountains and the foothills of Samarkand and Djizack, then rising abruptly to the high peaks (3000-4000 m) of the Turkestan, Zerafshan and Gissar mountains along the eastern Kyrgyz and Tadjik borders.

These high mountains, dissected by large valleys (e.g., Fergana, Zerafshan, Kashka-Darya, Surkhan-Darya, etc.) feed the main rivers of Uzbekistan. The Turanian plain is composed of pre-Quaternary and Quaternary formations originating from shallow sea sediments and covered by alluvial deposits from the main rivers fed by the eastern mountains and with eolian sand from the Karakum

Desert in Turkmenistan, through the sandy Kyzylkum covering most of Uzbek low land to sandy Moyunkum in southern Kazakhstan, extending northward on the flat Betpak-Dala steppe. To the west of Uzbekistan, gypseous formations, some 150-200 m above the Aral Sea depressions, form the Ustyurt plateau. The plateau is deeply dissected and contains countless endoreic salty and gypseous depressions. It ends in the east in high cliffs ('chinks') plunging some 100 m on to the shore of the Aral Sea and the Amu-Darya delta.

The Amu-Darya Delta and the Aral Sea

The 40,000 km² of the Amu-Darya delta is sliced up by many dry riverbeds, marshes and small lakes, resulting from the change of course of the Amu-Darya River, after flowing into the Sary-Kamysh lake (drainage lake of the irrigated Khorezm region) and the Ouzboi Valley to the Caspian Sea (Létolle and Mainguet, 1993). The whole Amu-Darya delta is strongly affected by eolian erosion, which adds recent and present sand deposits to the Kyzylkum Desert.

The Kyzylkum Desert

To the east of the Amu-Darya delta lies the Kyzylkum Desert covering some 300,000 km², stretching to the south-west of the Amu-Darya river into the sandy Karakum Desert in Turkmenistan, and to the north-east of the Syr-Darya River into the sandy Moyunkum Desert west of the Balkash lake in southern eastern Kazakhstan. The Kyzylkum is mostly covered with recent eolian '*barkhans*' and sand dunes, patched with '*takyr*' and salty '*solonchak*' depressions such as Ayagakytma, Minbulak, etc. Most of this low rainfall region is devoted to sheep, goat and camel husbandry on rangeland. Along the Amu-Darya and Syr-Darya rivers, irrigated cultivation is dominant with the large-scale production of cotton, fruit trees and cereals.

The Mountains, Valleys and Rivers

Rising from the eastern Kyzylkum, the Jurassic Nuratau Mountains reach some 2100 m. The Zerafshan chains (2000 m) extend further south bisected by the Zerafshan Valley, which descends from 900 m to 300 m east to west and the Zirabulak-Ziadin ranges (1000 m) at the western end of the Pamir-Alai ranges. The Zerafshan River flows from the Turkestan Mountains (3500-5000 m) through the city of Samarkand and ends in the eastern Kyzylkum near the city of Bukhara. The Zerafshan Mountains extend into Tajikistan parallel to the larger Turkestan Mountains near Dzhizack and the Gissar ranges with Hazret-Sultan (4600 m), the highest peak in Uzbekistan, near the Tadjik border.

Separated by the Baisuntau ridges (3000-4000 m), the Qashka-Darya River flows south-west into the Karshi steppe, while the Surkhan-Darya runs south into the Amu-Darya river through the town of Termez. The Termez Valley is bordered by the Babatag ridges (2200 m) to the east on the border with Tadjikistan. Most of Tajikistan and Kyrgyzstan are covered with high mountains (Pamir-Alai, Tien-Shan), while Turkmenistan, Kazakhstan and most of Uzbekistan are flat or gently undulating.

Tashkent Eastwards

The Tashkent Hunger steppe, nowadays mostly cropped and irrigated, is the most eastern part of the Kyzylkum, extending into southern Kazakhstan towards the cities of Turkestan and Taraz. The Syr-Darya River, flowing into southern Kazakhstan, crosses it. It is bordered by the western Tien-Shan Mountains to the east, extending into southwestern Kazakhstan, the Moyunkum Desert, and the Turkestan chains to the south. Travelling east along the Syr-Darya River, the Fergana-Andijan Valley opens between the Tien-Shan mountains (3500-4500 m, near Pskem, Chatkal, etc.) to the north and the Turkestan ridge and the Pamir-Alai mountains (5000 m and more) to the south along the Kyrgyz border. This entire region is geologically relatively young and earthquakes and movements are frequent.

SOIL

The desert soils of the Middle Asian rangelands evolved under semi-arid and arid conditions. They are characterized by low organic matter (<1%), a high level of calcium carbonate, often alkaline or saline and associated with gypsum, and a low agricultural potential. They have unfavourable water-physical and physico-mechanical properties, poor structural characteristics, and often a high bulk density and associated compaction. Most of these soils have evolved from alluvial, colluvial or eolian loessic deposits with little weathering of the parent rock. They have been intensively studied for their agricultural development potential because of the availability of irrigation water, mainly from the Amu-Darya and Syr-Darya Rivers and in relation to the Aral Sea problems (Létolle and Mainguet, 1993). As an example, three main groups of soils may be distinguished among the soil types recorded in Uzbekistan:

- *Sandy aeolian* soils (13.3 M ha), sand dunes of the Kyzylkum, on the *chol* (desert and semi-desert), and some agriculturally important loess deposits on the *adyr* (semi-arid foothill) .
- *Grey-brown* (11 M ha) and *Sierozem-grey* soils (3.8 M ha), on pre-desert and steppe, on the *chol* and the *adyr*.

- *Solonchak* and *solonetz*, azonal soils (1.5 M ha), or the *chol*, mostly in depressions, and *takyr* (2.8 M ha), with a high saline water table.

The first group is poorly developed. The other two groups have resulted from a slow evolution of the substrate, that is strongly affected by various physical and chemical processes, low organic matter content, a consequence of the low vegetation cover on the chamaephytic steppe, the presence of soluble salts, and alternating wet and dry periods throughout the seasons. This is the case for *solonchak* soils because of their association with the underlying saline water table and their topographical position in depressions that result in poor drainage and hydromorphy.

VEGETATION

The vegetation of lowland Uzbekistan well represents the vegetation of Middle Asia and the entire region. There are a number of similarities with the west Mediterranean arid lands of Spain-Morocco, through Baluchistan and the Chinese border. The Uzbek rangelands belong mostly to the Aralo-Caspian sub-province of the Irano-Turanian Province in the Mediterranean Steppe Sub-Region (Le Houérou, **in press**). The Irano-Turanian Province is a large territory stretching from north-western China, and Central and Middle Asia, to Mesopotamia, Anatolia, and the Arabian Peninsula. It also includes the near by Irano-Balutch Sub-Province to the south east, the Mesopotamian and the Anatolian Sub-Province to the southwest, and the Arabian sub-Province to the south.

The Steppe Sub-Region of the Ibero-Maghribian Province, including the Spanish Iberian Sub-Province and the North-African Maghribian Sub-Province, is analogous to the steppe Sub-Region of the Irano-Turanian Province. From a bioclimatic point of view, the Irano-Turanian and the Ibero-Maghribian Provinces are comparable with dominant winter precipitation and hot dry summers, except that the Irano-Turanian Province has much colder winters, preventing winter plant growth even when soil water is available. The botanic similarities between the Aralo-Caspian Sub-Province and the two sub-provinces of the Ibero-Maghribian Province are substantial since most genera (80 %) and about 10 % of the species are common to both provinces (Le Houérou, 1995). Vegetation types and physiognomy are similar.

The flora of the Irano-Turanian Province is extremely rich. Uzbekistan harbours 3,110 species of vascular plants, 366 of which are endemic. Turkey has some 11,000 species and subspecies, with a 32 % rate of endemism. The territory of 'Flora Iranica' (1963-1999), including Iran, Afghanistan, Baluchistan, and part of Azerbaijan and Turkmenistan, counts some 15,000 species, of which about 35 % are endemic. The Ibero-Maghribian Province possesses slightly over 2,680

species, 670 of which are endemic. The Irano-Turanian province extends to some 10 M km² while the Ibero-Maghribian covers 628 000 km², i.e., the same size as the Mesopotamian Sub-Province and a similar number of plant species. (Le Hou  rou, **in press**). The steppe vegetation is characterized by a number of life forms classified as follows (Raunkiaer, 1934):

- **Small trees** = micro-phanerophytes (trees 2-8 m in height), e.g., *Haloxylon aphyllum*, *Calligonum* sp.
- **Tall shrubs** = nano-phanerophytes (tall shrubs 0.50-2 m in height), e.g., *Salsola richteri*, *S. paletziana*, *Ephedra* sp.
- **Small shrubs** = chamaephytes (dwarf shrubs with buds about 10-50 cm above ground level), e.g. *Artemisia diffusa*, *A. terra-albae*, *A. turanica*, *A. kemrudica*.
- **Crassulescent halophytic chamaephytes** = mostly of the Chenopodiaceae family, characteristic of saline soils, e.g., *Salsola* spp. *Suaeda* spp.
- **Succulent glycophytic chamaephytes** are species belonging to the CAM carboxylation pathway species, e.g., *Crassulaceae* spp., *Apocynaceae* spp., *Asclepiadaceae* spp., and *Euphorbia* (subgenus *Tithymalus*)
- **Perennial grasses and biannuals** = hemicryptophytes (with buds on or slightly above the soil surface represented by bunch or tussock grasses), e.g., *Agropyron* sp., *Festuca* sp., *Stipagrostis* sp., *Poa bulbosa*, *Stipa parviflora*, etc. Some of these could be classified as ephemeroids very common in the Aralo-Caspian Sub-Province (perennial dwarf grasses and sedges with a short spring vegetative cycle), e.g., *Poa* or *Carex* sp.
- **Geophytes or cryptophytes** have their renovation buds underground, e.g., *Iris songarica*, *Allium* sp., *Merendera* sp. etc.
- **Annuals = therophytes**, also called 'ephemerals', as they live for only a short time during spring, e.g., *Bromus* sp., *Eremopyrum orientale*, *E. bonaepartis*, *Senecio subdentatus*, *Malcolmia grandiflora*, etc.

These life forms common in Middle Asia, when dominant, constitute as many common physiognomic types of steppes and rangelands that may occur from northwest China to northeast Spain. The vegetation life forms of the Aralo-Caspian Sub-Province are dominated by hemicryptophytes and chamaephytes with some rare small trees, and comparable to the one found in the Ibero-Maghribian Province. However, the chamaephytes, hemicryptophytes and ephemeroids with some characteristic micro- and nano-phanerophytes (e.g. *Haloxylon aphyllum*, *H. persicum*, *Calligonum* sp.), are prevailing in the vegetation of the arid and semi-arid zones of Uzbekistan and on the Middle Asian rangelands.

In mountainous areas of Tajikistan, Kyrgyzstan, eastern Uzbekistan, southern Turkmenistan, and Kazakhstan, forested areas with large trees such as *Juniperus* sp., *Ulmus* sp., *Acer* Sp., *Amygdalus* sp., *Juglans* sp., *Pyrus* sp. are common, while large population of dense *Populus* sp. ("Turanga", "Tutangyl") covers the phreatophyte "Tugai" forest along the mains rivers and water course (Gintzburger et al., 2003).

LAND USE AND AGRICULTURAL TRENDS (1992-2002)

During the Soviet Era, the Central Asian republics were provided with wheat from Russia, the Ukraine and mostly from Kazakhstan to augment their local production. In Uzbekistan, cotton, the 'white gold', was the major crop and was swapped for staple foods. After the fall of the Soviet system, the new republics had to produce their own wheat, mainly under rainfed conditions, and large potential food and feed deficits may be expected considering the human and livestock population needs by 2020 (Nordblom et al., 1997). Increasing wheat production had to be achieved by increasing yields and acreage given over to wheat production, both on irrigated and rainfed land, even to the detriment of the best rangelands, as happens in North Africa and the Middle East. All other crops indicate a fluctuating and unstable agriculture in terms of crop acreage harvested and yield collected during the post-Soviet Era. Trends in agricultural production all the Middle Asian countries are as follows:

Fertilizers

Trends in fertilizer use are good indicators of the health of the agricultural sector in a country. Uzbekistan is the largest user of all fertilizers (Table 3) in the region with some 7-800, 000 tonnes/ year (self sufficient, only 1 % import) and far ahead of all other countries of the region. It is followed by Turkmenistan (76, 000 t in 1998, 117, 000 t with 44 % imported in 2001), then Kazakhstan (13, 000 t in 1998, 50, 000 t - all imported, and small export), Tajikistan (dropped from 37, 000 t in 1998 to 12, 000 t with 67 % imported), and finally Kyrgyzstan (29, 000 t in 1998 to 7, 000 t, with 100 % imported).

Most remarkable is the large amount of nitrogen fertilizers used by Uzbekistan (559, 000 t in 2001) and phosphate (126, 000 t), and only 8, 000 t of potash fertilizers. Turkmenistan is the largest user of potash fertilizer with 14, 000 t in 2001 and nearly 100, 000 t of nitrogen. Quite astonishingly, Kazakhstan, with the largest area of rainfed cropping, is only using 5, 000 t of phosphate fertilizers in 2001, though increasing its use from 200 t in 1998 to about 5, 500 t in 2001, and a modest total of 42, 000 t of nitrogen. This may reflect the difference between rainfed and irrigated cropping between these countries.

In 2001, Uzbekistan was the largest regional fertilizers producer (706, 000 t/year, 81 % nitrogen, 19 % phosphate), followed by Turkmenistan (65, 000 t/year, 92 % nitrogen, 8 % phosphate), Kazakhstan (24, 000 t/year, 32 % nitrogen, 68 % phosphate) and Tajikistan (4, 000 t/year, all nitrogen). These figures contribute to explain the amount of fertilizers used in the different countries and the yields obtained in different irrigated and rainfed sectors of crop production.

Table 3. Total fertilizer use in the Middle Asia republics (2001).

Fertilizer	Kazakhstan	Kyrgyzstan	Uzbekistan	Tajikistan	Turkmenistan
Total t yr ⁻¹	50,400	7,000	693,300	12,100	117,000
Nitrogen, %	83	100	81	100	84
Phosphate, %	11	0	18	0	4
Potash, %	6	0	1	0	12

Wheat (Irrigated and Rainfed)

From 1992 onwards, the area sown to wheat in Uzbekistan more than doubled from a mere 600,000 ha to nearly 1.5 M ha in 1997, then declined to 1 M ha in 2001 (FAO, 2001) to come back to 1.5 M ha in 2002 (FAO, 2002). Wheat yields rose from 1.4 t ha⁻¹ (1992-94), to 2.3 t ha⁻¹ (1995-2000), and to a record yield of 3.7 t ha⁻¹ in 2001 and 3.3 t ha⁻¹ in 2002. Wheat yield increased linearly over the years 1992-2001 with an extra 200 kg grain ha⁻¹ each year, independently of climatic conditions and in spite of poor years (1999-2001). It is quite clear that in Uzbekistan the high wheat yield could only be achieved under irrigation, and on land usually assigned to cotton and possibly rice production. Wheat yield in 2002 in Kazakhstan (1.09 t ha⁻¹ on 11.6 Mha) and Tajikistan (1.25 t ha⁻¹ on 290 ha only) reflect mostly rainfed cropping. The one obtained in Uzbekistan (3.2 t ha⁻¹ on 1.5 M ha), Kyrgyzstan (2.6 t ha⁻¹ on 0.5 M ha) and Turkmenistan (2.8 t ha⁻¹ on 730 ha only) indicates that irrigation is supplied.

Cotton (Irrigated)

During the same period, the area given to cotton production in Uzbekistan, completely under irrigation, gradually declined from approximately 1.7 M ha in 1992 to 1.4 M ha in 2001-2002, but maintained a stable yield of 2.4 t ha⁻¹ from 1992 to 2001. One could speculate that some of the irrigated cotton area was re-assigned to wheat production in Uzbekistan. In 2002, cotton seed yield reaches an average 2.5 t ha⁻¹ in Kazakhstan (167, 000 ha) and Kyrgyzstan (36, 000 ha),

1.7 - 1.9 t ha⁻¹ (260, 000 ha) in Tajikistan, and dropped from 2.1 to 1.1 t ha⁻¹ in Turkmenistan (510, 000 ha) from 2001 to 2002

Acreage under cotton cropping drastically increased in Kazakhstan between 1992 (110 000 ha) to some 170 - 184, 000 ha in the year 2000-2002, 21,000 ha to 36, 000 ha in Kyrgyzstan, remained fairly stable (220-260 000 ha) in Tajikistan, and dropped slightly in Turkmenistan (570-600 000 ha in the early nineties) to some 500, 000 in 2001-2002.

Rice (Irrigated)

Rice acreage in Uzbekistan, also under irrigation, remained stable with some 150,000-190,000 ha until 1999 and then decreased to only 37,000 ha in 2001 to rise back to nearly 60 000 ha in 2002. Rice yield remained stable over the whole period (mean 2.5 t ha⁻¹), in spite of a sharp reduction in 1999 (1.23 t ha⁻¹) and a record yield of 3.6 t ha⁻¹ for 2001 and 2.4 t ha⁻¹ to be confirmed in 2002. Kazakhstan (65, 000 ha), Tajikistan (10, 000 ha) and Kyrgyzstan (6, 000 ha only) yield some 2.9 - 3.1 t/ha in 2002, while Turkmenistan (42, 000 ha) produce 10.1 t/ha of rice (paddy) in 2002. During 1992 - 2002, Turkmenistan saw its rice area fluctuating between 28 - 70, 000 ha, and 10-19, 000 ha in Tajikistan. It increased in Kyrgyzstan from 2, 000 to 6, 000 ha, while it dropped sharply in Kazakhstan from some 120, 000 ha in 1992 to about 65, 000 ha in 2002.

Barley (Rainfed)

Barley is essential to livestock as supplementary feeding; it displays a good indication of the priorities assigned to livestock production, especially to small ruminants fed on rangelands. Most interesting is that barley cropping on rainfed areas in Uzbekistan decreased gradually from 300,000 ha in 1992 to only 80,000 ha harvested in 2001. The barley yield was stable during 1992-2000 at 0.93 t ha⁻¹, but fell to a low 0.25 t ha⁻¹ because of very poor rainfall in 2001. In fact, the barley overall yield decreased slowly over the years from 1992 to 2001 by approximately 60 kg grain ha⁻¹ year⁻¹. This may indicate that not only were the rainfall seasons poor at the end of the 1990s, but also that barley cropping was relegated to the lower rainfall zones and onto the poorest soils.

It is also quite probable that some of the barley production areas and also new rainfed cropping areas brought into cultivation through range clearing were assigned to wheat production. This was at the expense of the best rangelands in the best rainfall zones on the adyr and also in the pre-desert areas where extra run-off could be secured. This new burden may contribute to increase the current poor condition of rangeland in Uzbekistan.

During the 1992 - 2002 period, the barley area harvested in Kazakhstan dropped from nearly 5.6 M ha to 1.7 M ha, 263, 000 ha to less than 70, 000 ha in Kyrgyzstan, 55, 000 ha to 22 000 ha in Tajikistan, and fluctuating in Turkmenistan around 50-60, 000 ha with a high 147, 000 ha in 1995. As a result, total barley production dropped radically in all these countries (Fig. 3) with the exception of Kyrgyzstan, clearly showing the pressure put on animal feed in the region.

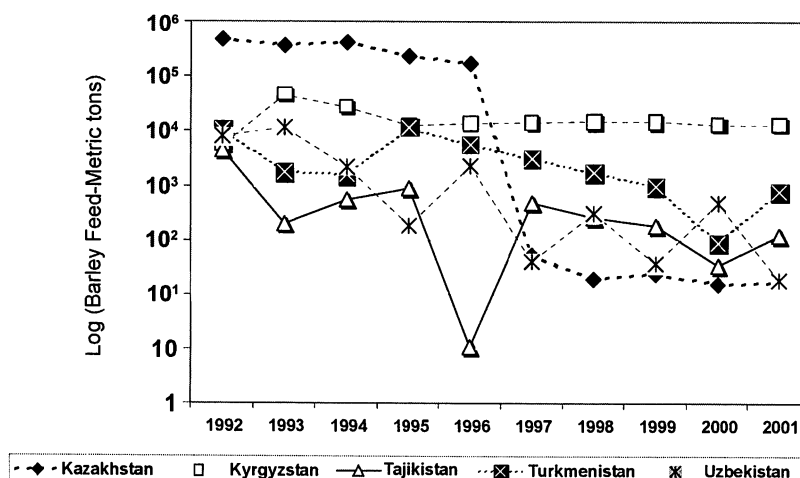


Fig. 3. Trends in barley feed produced in the five countries of Middle Asia between 1992 - 2001 (FAOSTAT 2002).

Oats (Rainfed and Irrigated)

Oats harvested decreased in Kazakhstan from 448, 000 ha in 1992 to 143 000 ha in 2002 with a significant drop in 1998, in Kyrgyzstan (4,000 ha to 1,300 ha), and Tajikistan (3400 ha to about 800 ha). Produced in very limited quantity in Turkmenistan and Uzbekistan, it appears to have completely ceased to be produced in 1997 in these two countries.

Maize

Maize production is mainly irrigated and assigned to dairy cattle feeding. The area harvested remained stable in Kazakhstan (around 100, 000 ha) after a sharp drop in 1997 - 99 (60, 000 ha). The yield increased steadily after 1997 to reach 4 t/ha in 2002. The same trends are observed in Kyrgyzstan (54, 000 ha in 1992 - 70, 000 ha in 2002), but with better yield (5-6 t ha⁻¹) achieved in 2001-02. Maize in Tajikistan stayed stable in terms of area harvested (11-13, 000 ha). In

Uzbekistan, the maize area harvested decreased sharply from nearly 100, 000 ha to about 40, 000 ha with yield reaching 5.9 t ha⁻¹ in 2002. The same trend was observed in Turkmenistan (43, 000 ha in 1992 to 15, 000 ha in 2002) and yield dropping from nearly 4 t ha⁻¹ to 0.7 t ha⁻¹ after 1997.

Maize for forage and silage under irrigation has also decreased from 2.25 M ha in 1992 to a mere 100, 000 ha in 2002. This is mainly in relation to the strong decline in cattle in this country. The areas under maize for forage and silage has declined by half in all other countries with 40, 000 ha left in 2002 in Kyrgyzstan, 15, 000 ha in Tajikistan, 27, 000 ha in Turkmenistan and 110, 000 ha in Uzbekistan with fluctuating yield ranging from 10 to 20 t ha⁻¹.

Mixed Grasses and Legumes

Feed coming from this resource remained stable in terms of area and yield, ranging from 6 to 12 t/ha in each country.

LIVESTOCK PRODUCTION

The Uzbek agricultural statistics available for the transition period indicate that the numbers of camels (25,000), cattle (5,264,000), goats (924,000) and horses (140,000) remained fairly stable during 1992-2001 (FAO, 2001). However, the sheep population fell from 8.7 M heads during 1992-96 to 7.8 M heads after 1996. It seems to be rising again to over 8 M heads after 2000.

A recent limited livestock survey in Uzbekistan indicates that shepherds tend to increase the number of goats in their flocks to obtain a higher meat off-take as goats have better twin birth than sheep (USDA, 2001). Milk production and milk products from small ruminants rose on all rangelands, once an important issue, are also becoming again quite critical to the region (Hirata, 2002).

- **Sheep:** The steady drop in sheep number in Kazakhstan from 33.9 M head (1992) to 9.2 M heads (2002) is extraordinary. The same strong trend is observed in Kyrgyzstan with 9.2 M heads in 1992 to a stable 3 M heads after 1998 and Tajikistan (2.5 M heads in 1992, 1.5 M heads in 2002). The sheep flock remain quite stable in Uzbekistan (about 8 M heads) and Turkmenistan (5.5 - 6 M heads) between 1992 - 2002. All over the five countries, shepherds tend to replace the Soviet omni-present Karakul sheep producing the famous "Astrakhan" pelt, with sheep producing more meat, much in demand, instead.
- **Goats:** Meat, being in high demand, and as less demanding goats flocks may survive well on poor rangelands, the number of goats increased gradually from 0.7 to 1.3 M heads in Kazakhstan, from 0.3 to 0.7 M heads in Kyrgyzstan and 0.22 to 0.37 M heads in Turkmenistan. It remained fairly stable in Uzbekistan and Tajikistan (0.8-0.9 M heads).

- **Horses:** It remains stable in Kyrgyzstan (300-350, 000 heads), Uzbekistan (110 - 150 000 heads) and Turkmenistan (17-20, 000 heads). It increased by nearly twofold in Tajikistan (47 000 - 71 000 heads), while it declined from 1.7 M to 0.99 M heads in Kazakhstan between 1992 and 2002.
- **Camels:** Its population dropped from 145, 000 to about 100, 000 heads in Kazakhstan, but remained nearly constant in Turkmenistan (40, 000 heads), Uzbekistan (25, 000 heads), Kyrgyzstan (50, 000 heads) and Tajikistan (45, 000 heads)
- **Cattle:** The number of cattle decreased steadily in Kazakhstan from 1992 (9 M heads) to about half in 2002 (4.3 M heads). It remains stable in Kyrgyzstan and Tajikistan (about 1 M heads), Turkmenistan (8-900, 000 heads) and Uzbekistan (5 - 5.5 M heads). The number of buffaloes stock in Kazakhstan has also declined from 12, 000 heads in 1992 to about 9, 000 heads in 2002. It may indicate that irrigated land allocated to forage production (alfalfa, maize, etc.) for cattle has also significantly declined in Kazakhstan.
- **Pigs:** The decrease in Christian population after 1992 in all these predominantly Moslem CIS countries have triggered a drastic reduction of the pig production units and number. The reduction is twofold in Kazakhstan, fourfold in Kyrgyzstan, sixfold in Turkmenistan and Uzbekistan and about two hundred (1/200) fold in Tajikistan.

Mutton and Goat Meat

The off-take from the small ruminant flocks dropped down by half in Kazakhstan (to reach 97, 000 t in 2002), Kyrgyzstan (38, 000 t), and Tajikistan (13, 000 t), while slightly increasing in Turkmenistan (57, 000 t) and Uzbekistan (81, 000 t) between 1992 and 2002. The mutton and goat meat supply per capita and per year declined comparably in the three first countries to reach in 2002, 6.0 kg in Kazakhstan, 7.7 kg in Kyrgyzstan, 2.1 kg in Tajikistan; it remains stable during the last 10 years in Turkmenistan (about 11 kg/cap/year) and 3.2 kg in Uzbekistan. This indicates the upward trend in sheep and goats numbers that may slowly take place in Kazakhstan, Kyrgyzstan and Tajikistan after the decline observed over the past 10 years.

Milk Production

Milk and milk products are essential food supply for the local population as fresh milk, butter, yogurt and cheese. Total milk production (1992-2001) drastically dropped (1993-97) in Kazakhstan, decreased steadily in Tajikistan, while remaining fairly stable in Uzbekistan. It even nearly doubled in Turkmenistan and slightly increased in Kyrgyzstan (Fig. 4).

During the same period (1992-2001), the "Whole Supply - Milk" per capita did not significantly change in Uzbekistan (132 kg). It declined in Tajikistan (75 to 52 kg/capita/year), and increased in Turkmenistan (75 to 52 kg), in Kyrgyzstan (138 to 184 kg) and Kazakhstan (137 to 206 kg).

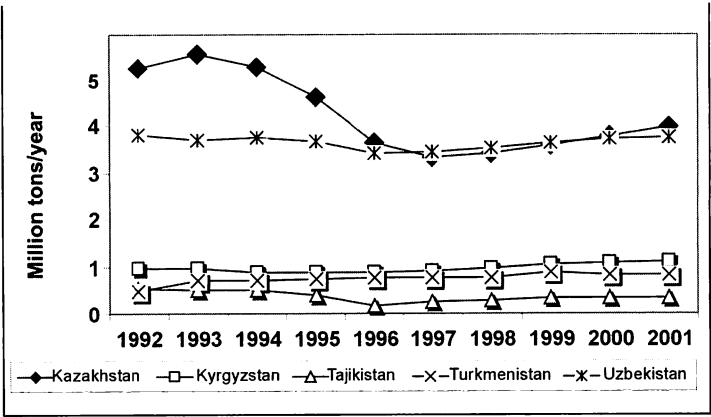


Fig. 4. Trends in milk production (million tonnes) produced in the five countries of Middle Asia between 1992 - 2001 (FAOSTAT 2002).

SMALL RUMINANTS AND CROPPING: FUTURE CHALLENGE

Desertification may affect at diverse level the five countries of Middle Asia as competition is taking place for agricultural land between food and feed production. Wheat and meat are much in demand for increasing the human population. Some indication of the trends may be documented from the Uzbek example. Looking at the quadratic relationship between small ruminants and wheat area harvested in Uzbekistan between 1992 and 2000, it can be seen that the more wheat cropped, i.e., over 1 M ha, the smaller the sheep and small ruminant populations (Fig. 5). If the new wheat areas extend into the best rangeland and barley producing areas, that result is not surprising.

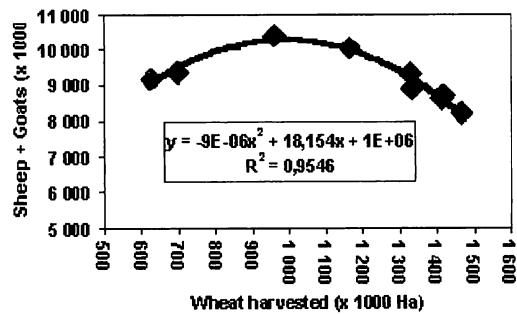


Fig. 5. Total "Small Ruminant" as a function of "Wheat Harvested" in Uzbekistan (1992-2000).

There is also a positive linear relationship between barley grain production each year and sheep numbers or total number of sheep and goats (Fig. 6). This substantiates the fact that barley in Uzbekistan is important for sheep and small ruminant complementary feeding, i.e., the less barley cropped, the smaller the sheep and goat populations. The same trends may apply to other countries, especially when one looks at the trends of barley feed produced in all the five countries (Fig. 3).

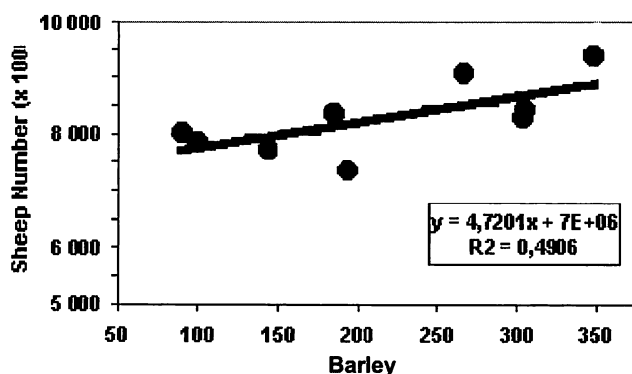


Fig. 6. Number of "Sheep" as a function of the "Barley" area harvested in Uzbekistan.

It is also clear from the statistical data available and estimates that 80% of the barley produced is fed to small ruminants, and that the daily supply of barley grain to small ruminants has steadily and linearly decreased between 1992 and 2001, from 720 g/head small ruminant/day (1992-95), to 436 (1996-97), 206 (1998-2000) to a low of 49 g per head small ruminant per day in 2001. In terms of animal feeding, this may indicate higher pressure on feed resources in rangeland, as barley grain is no longer available. This should raise serious concern amongst decision-makers with regard to increased rangeland degradation and new desertification trends in the country.

The Pastoral System

For ages, nomadic and transhumant pastoralists of Middle and Central Asia have used the desert, steppe and mountain rangeland (Vinogradov and Mamedov, 1975) for hunting and grazing (Tashbaeva et al., 2001). Before the Soviet Revolution, the desert livestock industry and Karakul sheep breeding and milk production was based entirely on rangeland forage resources. In search of the best forage, pastoralists moved from place to place depending on the availability of forage and fuelwood. They also used to travel long distances from winter to

summer vegetation and vital water supplies for their flocks. This also allowed them to minimize feed storage and the need for supplementary feeding.

In winter, the *chol* and sandy deserts were preferred as animals could shelter and graze between the sand dunes. In spring, the flocks would graze ephemeral and ephemeroid plants on the *chol* and *adyr*, which provided pregnant animals with nutritious food and plenty of water, thus reducing the need for frequent watering of the flocks. As the dry summer approached, pastoralists move closer to wells and watering points, mostly on the *adyr* and the foothills, to graze the dry ephemerals, shrubs and perennial grasses.

During the summer and autumn, they would climb up on to the *tau* (mountain range), and when possible the *alau* (ranges and pastures above the tree line), high into the mountains, until the first snow and frost arrived. With the approach of winter, they would descend and progress slowly back to the lowland and sandy desert. The early pastoral industry mostly bred sheep (fat-tail type: Karakul, Gissara sheep), and dromedary in Uzbekistan and Turkmenistan (Arvana dromedary), and Bactrian camels in southern Kazakhstan and northwards.

The Stalin collectivization and forced settlement of nomads in the 1930s catastrophically and abruptly stopped nomadic movement between different ecological zones, thus totally altering the livestock systems in all Middle Asian countries. With the influx of Russian colonization and the planned socialist system forcibly implemented through *sovkhoses* (State farms) and *kolkhoses* (collective farms) in new areas of the desert, production of Karakul sheep increased because of high pelt values. This was achieved by improving fertility, breeding and intensive feeding systems. Slowly, the new livestock system managed to get back into equilibrium after a radical decrease in animal numbers, and, the need for a better use of rangeland resources in different ecological zones prevailed.

Some of the flock movements and long migrations were recognized as being beneficial and were re-established by the allocation of appropriate grazing land to *sovkhoses* and *kolkhoses* in different ecological zones (Kerven, 2003). These rangeland areas remained a priority issue in Middle Asia up to the late 1980s because of the growing demand for livestock products and Karakul wool and pelts by the rapidly growing population, and the increasing allocation of land, capital and water to cotton production.

The market changes and privatization, which started in the early 1990s, caused imbalances and dramatic reductions in agricultural stocks, production and productivity. Partly, the decline in livestock numbers can be attributed to the deterioration in terms of trade for producers, resulting from the liberalization of markets, while the price of products is still under State control. Severe harvesting of range vegetation for feed and fuel and lack of winter forage, a typical constraint of the region with severe winters and poor maintenance of water wells, have accelerated rangeland degradation.

RANGE DEGRADATION AND REHABILITATION

For the last 50 years, regular annual multi-disciplinary field expeditions and surveys to collect living plant material and seeds were carried out in Middle and Central Asian regions. Germplasm conservation of taxonomically and geographically various species was organized in close collaboration with the Vavilov Institute of Plant Development (St. Petersburg) and by Middle Asian scientists. This was complemented by field evaluation studies of rangeland species collected and range regeneration techniques developed. Due to a substantial disruption of the pastoral and scientific systems in the steppe of Middle and Central Asia, during the last 5-6 years, many fodder reserves, 30-40-year-old trees and *Saxaoul* plantations have been damaged.

Severe fuelwood collection and cropping on the best soils, mainly on *Artemisia* steppe and the *adyr*, have slowly reduced the vegetation cover. As a result, the native grazing land has been rendered unproductive with a long-term decline in productivity and functional disorder resulting in desertification and in a loss of natural resources and potential. The poor management or destruction of the native woody shrub/dwarf shrub vegetation or forestry plantations in many arid and semi-arid areas has lead to land degradation by wind and water erosion preventing the natural regeneration of rangeland plants. Shifting sand dunes in the Kyzylkum Desert cover approximately 0.5 million ha and are devoid of vegetation (Kharin, 1994).

The past and more recent condition of the desert and semi-desert regions has lead decision-makers and well informed scientists to take urgent measures to protect and raise the current low productivity and, when necessary, to rehabilitate what has been damaged by human activities in the Middle Asian rangeland (Nechaeva, 1985) and also in other similar arid and semi-arid regions of the Mediterranean world (Le Hou  rou, 2000).

Depending upon particular landscape and environmental conditions, the following rangeland species proved to be of most value for range introduction and eventually forage crop cultivation and seed production: *Haloxylon aphyllum*, *Calligonum* spp., *Salsola paletzkiana*, *S. richteri*, *S. orientalis*, *S. gemmascens*, *Halothamnus subaphylla*, *Kochia prostrata*, *Camphorosma lessingii*, *Artemisia turanica*, *A. halophylla*, *A. diffusa*, *Eurotia ewersmanniana*, *Astragalus agameticus*, *Poa bulbosa* and other grass species. Moreover, other species such as *Ephedra strobilacea*, *Agropyron desertorum*, *Carex physodes* and some annual *Salsola* spp. were introduced into man-made pastures as components of improved or regenerated rangeland.

Among pastoralists in middle Asia, the most recognized and valuable techniques for tree and shrub establishment and rehabilitation of rangeland appear to be the creation of long-term artificial range and pasture for use in different

seasons and, if possible, for use all year round. In terms of valuable forage phyto-genetic resources, *Agropyron* spp. collected in Middle and Central Asia in has been successfully introduced in large areas of the US Great Basin as tame pastures (West, 1983a; 1983b).

Also valued by shepherds are the creation of forest shelterbelts using *Haloxylon* spp. and other woody shrubs, the increase of fodder production on salt-affected and *taky*r rangelands, and the establishment of irrigated pastures using various sources of underground and brackish waters (Gaevskaya and Salmanov, 1975). All range improvement or rehabilitation operations in Middle Asia are carried out by direct seeding (including aerial seeding), in contrast to most other range improvement operations that transplant nursery-grown seedlings as in West Asia and North Africa (Le Houérou, 2000). This is mostly because Middle Asian rangelands are often snow-covered in winter, conditions that greatly facilitate direct seeding, and are favourable for germination when temperatures reach a suitable lower limit. Special equipment was developed for direct range reseeding in Middle Asia - North Africa, the Middle East and Australia (Gintzburger, 1987).

CONCLUSIONS

If the new challenge for the Republics of Middle Asia is to produce more food, especially wheat, for their population, then this has to be carefully balanced in terms of expanding new wheat-cropping areas on to irrigated land, the best rainfed areas, the barley-growing areas and the best rangeland. This has a direct bearing on the small ruminant flocks that are producing the much-needed meat and derived milk products for the population. More small ruminants may mean potential increase in range degradation and desertification. There is a need to optimize both grain and meat and milk production and to balance available natural resources for a sustainable future agriculture in Middle Asia.

It is, therefore, important to evaluate the current state of the native flora and the qualitative and quantitative condition of the vegetation cover of fragile rangeland, especially during the delicate transition period to market economy that the Middle and Central Asian countries are currently undergoing. Local agronomic and rangeland scientific expertise and "know-how" are still available and should be used without delay.

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Management Systems for Crop Production in Kazakhstan

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ABSTRACT

Central Asia, including Kazakhstan, is of strategic interest to the West for the maintenance of global peace and security. Great agricultural potential exists in the Kazakhstan for sustainable and economic development. Soils are rich, especially in the northern Kazakhstan, and used for traditional grain production in the past. External technical and financial supports are needed to develop a market-oriented agriculture. The objective of this paper is to analyse the impact of historical management strategies on the soil resources and grain production, and, where appropriate make comparisons with North America, especially Canada, which has a somewhat similar agriculture and agroecology.

About 25 million (M) hectares land was used between 1954 and 1964 for grain production in Kazakhstan this continued until the collapse of the Soviet Union; since then it has been reduced to 17 M ha. Yields were highest between 1965 and 1994. Kazakhstan can potentially produce more than 20 m ton grain per year. The use of agrochemicals and adaptation of new technologies such as conservation tillage, agroforestry, crop residue management, and use of appropriate amount of fertilizers can help to achieve this. Techniques that increase organic matter in the soil must be adopted. Crop diversification could also be a vital part of the revolution.

On-farm experimental studies are needed in different eco-regions of the country. Sustainable increases in crop production can also support the economical development of the country. Irrigated agriculture is very important for crop production, but Kazakhstan has not yet reached a level of optimising the land and water resources use for agriculture.

INTRODUCTION

As in the North America, large-scale changes have occurred in Kazakhstan's agriculture in the second half of the 20th century. In the period of 1954-56, over 25 million (M) hectares of virgin grassland were plowed to introduce and maximize

spring wheat production (Suleimenov, 2000). While semi-desert and desert areas cover large area in Kazakhstan, Black soils (Chernozems or Mollisols), rich in organic matter and nutrients, are widespread in the *Boreal Steppe* (Prairies in the North American context) region of Kazakhstan. The Kazakh plateau (Turgay) in the north, which occurs just on the Siberian continental divide, has a higher elevation than central Kazakhstan, and therefore receives somewhat higher precipitation than most part of the country.

The southwestern part of the country is drier and more desert-like and is a closed basin, whereas the rivers originating in the northern and northeastern part (Irtysh, Ishim, Tobol, and others are connected to the large Ob River in Siberia) of the Kazak Plateau are connected to the Arctic Ocean. Northern Kazakhstan has three main soil zones, with their agroecological characteristics and associated potentials for agriculture: *Common Chernozems*, *Southern Chernozems*, and *Dark Chestnut* soils. Most of these soils would be classified as Mollisols in the US "Soil Taxonomy" (Soil Survey Staff, 1999).

Considerable agricultural potential exists in Kazakhstan for sustainable and economic development. External consultancy and support are needed to develop a market-oriented agriculture in Kazakhstan and indeed in the rest of the central Plateau of the Eurasian continent. After the collapse of Soviet Union, the regional dynamics have been characterized by continuous transformation, and opportunities for business development are emerging. A historic and unprecedented shift has taken place in the past 13 years in a region of strategic interest to the West, and one that is vital for the maintenance of global peace and security.

The objective of this paper is to analyse the impact of management techniques on the soil resources and crop production of Kazakhstan with specific reference to the history of grain production and the crop production constraints in relation to conservation tillage. Through international assistance Kazakhstan needs to develop policies and strategies to increase soil quality, especially the level of soil organic matter and fertility in comparison to virgin lands, so that a sound approach can be developed for sustainable crop production, conservation, and rehabilitation of the country's degraded lands. As there are broad geographic, climatic, and soil similarities between Kazakhstan and North America, the world's largest wheat producer, brief reference is made to comparative trends in both locations.

SOILS CLIMATE AND VEGETATION

Major soils of the Eurasian steppes are well known as the very dark coloured, base-rich soils called Chrenozems, or Mollisols in the USA (Soil Survey Staff, 1999), commonly occur in Ukraine, Russia, and Kazakhstan. As in the Canadian Prairies, these soils developed under grasses, but they may have been under forest

at an earlier time. In addition to North America, black soils are extensive in other parts of the world, e.g., Europe and South America. They are derived from mainly carbonate-rich parent materials and may be found in any moisture regime, but do not have permafrost. Such soils have enough moisture to support perennial grasses; they have thick black topsoil with a pH value around 7, and high base saturation, and are rich in organic matter and nutrients that can support good crop production. Mollisols lie generally between soils in arid regions (Aridisols) and those with a humid climate (Spodosols and Alfisols). Mollisols of northern Kazakhstan, like in Canada, are cool or cold and have a cryic temperature regime, and *udic*, *ustic* or *xeric* moisture regimes. Vegetation on these soils is mostly of grasses; those occurring on undulating topography and mountains have forest vegetation or mixed forest and grasses. Most of these soils are now cultivated and used for grain production.

The area covered by the Black soils in Eurasian Steppes is about 90 million ha. About half of this area, 42 m ha land, were cultivated during the time of virgin land cultivation between 1954 and 1964, and 25 million ha alone in Kazakhstan (Gossen, 1998; Suleimenov, 2000). The actual arable land in north Asia, east of Ural Mountains, is over 175 million hectares (Bot and Nachtergaele, 1999). A recent map of the intensity of agriculture in the world shows this reality (Fig. 1). Only 61% of the total potential lands in the Eurasian Steppes is cultivated. Due to limitation of moisture, agriculture is somewhat limited.

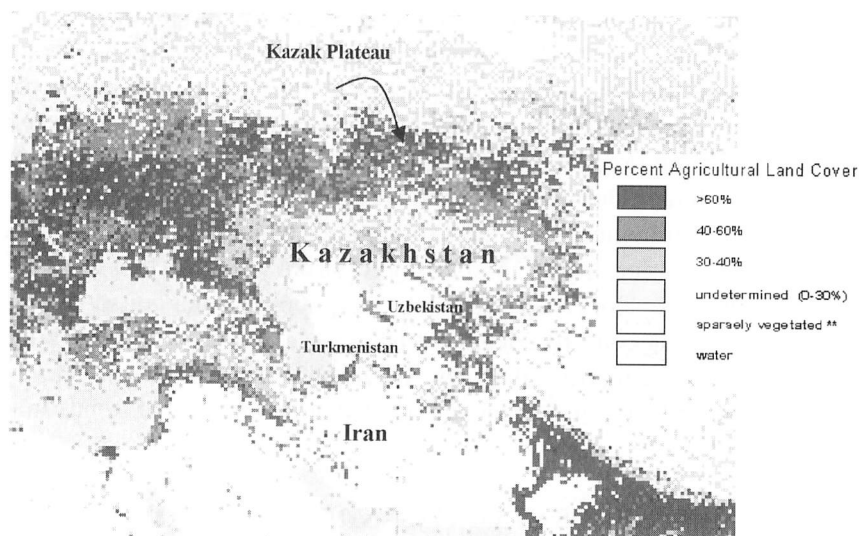


Fig. 1. Percent agricultural land cover classification in central and western Asia.
 (Source: K.L. Sebastian, GIS Analyst/Consultant Environment and Production Technology Division International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006).

Canada, being the second largest country in the world and one that is also highly mechanised, has only 68 M ha land (about 7.5% of the land area), with only about 33 M ha being annually used for crop production. About 293,000 farms (about 3% of the current population) exist on the agricultural land in Canada, and the number of farmers is decreasing every year (Acton and Gregorich, 1995). Average farm size in Saskatchewan is about 450 ha, but some farmers may have as much as 2000 ha.

Climatic conditions in North America are broadly similar to those in Eurasian Steppes. Cold semi-arid regions of the Northern Great Plains (Prairies) receive about 350–400 mm per year. These numbers show that the Canadian Prairies are analogous to those in the Eurasian Steppes. Rainfall in Saskatchewan varies between 250 to 450 mm per year, with a growing season of 100–120 days year⁻¹ (Cameron and Oram, 1995). Great similarities in soils, landscapes, geology, hydrology, and ecology exist between Canadian Prairies and northern Kazak Plateau, including the cultivation history. Large areas were opened for agriculture after the World War II in both regions.

In northern Kazakhstan, annual average precipitation is about 300 mm. In Shortandy, the annual rainfall is about 350 mm (Suleimenov, 1992), which is close to the average in the Canadian Prairies. Precipitation is lower in the central and southern arid and desert zones. Near the east and southeast Mountain regions, precipitation increases (Fig. 2). Figure 3 shows the average monthly precipitation and temperature in five different locations (Longmire and Moldashev, 1998). Average total annual precipitation is 277 mm and mean annual temperature is 1.6 °C. The locations that were used to produce this figure were Astana, Kostanai, Aktobe, Pavlodar, and Petropavlovsk. This pattern is quite similar to the Northern Great Plains of North America, specifically Saskatchewan.

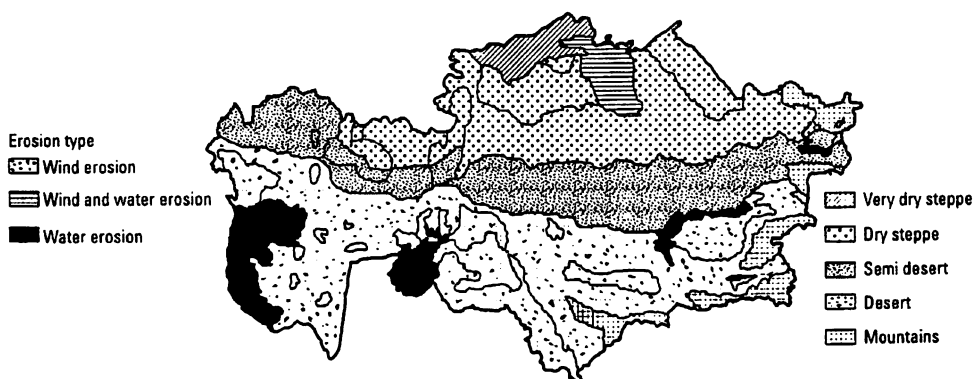


Fig. 2. Main ecological zones in Kazakhstan (from Gossen, 1998).

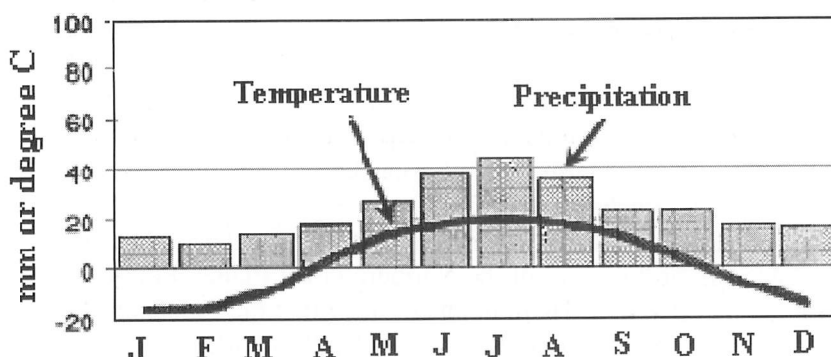


Fig. 3. Average monthly precipitation and temperature of five selected locations Astana, Kostanai, Aktobe, Pavlodar, and Petropavlovsk in northern Kazakhstan. (Longmire and Moldashew, 1998).

SOIL MANAGEMENT SYSTEMS

Recent Cultivation History

The cropping pattern and yields in Kazakhstan have changed drastically since World War II. While grain production between 1986 and 1990 reached about to 1 ha^{-1} and the yield has declined to about 0.65 ha^{-1} in 1994-96, both values are still much below the current world average of grain production. Nevertheless, these are indications that implementation of comprehensive research programs by the Baraev Kazak Research Institute of Grain Farming has played a key role with relatively higher yield. This Institute has kept close contact with Canadian research institutions, and the scientists were well informed about the research and development taking place in the Canadian Prairies. Gossen (1998) has provided an interesting historical perspective of cultivation and grain production in Kazakhstan, which should be considered when setting a new strategy for the Kazakhstan's northern grain belt. Table 1 shows the total cultivated area, grain production, and yield within the last 50 years. Considering the production pattern, one can recognise four periods. I (1946-54), II (1954-64), III (1964-94), and IV (1994-present).

Period I represents the initial state of grain farming. Period II involved the large- development and exploitation of virgin and marginal lands coinciding with similar land expansion in the Canadian Prairies. In this period, the yield per ha was somewhat higher (0.70 t ha^{-1}) than the initial period, but still much lower than the potential of the land. Suleimenov (1992) attributes these to the monoculture farming system. Due to application of fertilisers and other agro-chemicals (pesticides, herbicides) used for plant protection and the application of soil

Table 1. Cultivated area, yields, and total crop production between 1946 and 1996 in Kazakhstan.

Period	Cultivated Area	Yield	Total Grain Production
	---m ha---	---t ha ⁻¹ ---	---m t---
I. 1946-54	7.0	0.56	3.9
II. 1954-64	24.6	0.70	17.2
III. 1965-93			
1965-75	23.8	0.89	21.2
1976-85	25.3	0.96	24.3
1986-90	24.1	1.00	24.1
1991-93	22.2	0.94	21.7
IV. 1994-96			
1994	18.9	0.79	16.4
1995	18.9	0.50	9.5
1996	17.2	0.65	11.2

conservation measures, yield reached the highest point during Period III (1.0 t ha⁻¹). During this era, Kazakhstan produced the highest amount of yield in its history. Period IV typically represents the time of drastic reduction in both fertilizer and herbicide use. Grain production reverted to its primitive original phases, but this unexpectedly created ideal conditions for breeding locusts. Millions of dollars are spent by the Kazak Ministry of Agriculture to overcome this problem.

Considering the extent of dryland areas, the soils can produce much more than 20 m ton of grain per year. If they achieve the world average, they could revolutionize their agriculture. Consequently, this would strengthen the position of the producer to adopt the use of agrochemicals and new technologies such as the conservation tillage that can help to maintain soil quality. Crop diversification could be a vital part of this revolution. Intensification and crop diversification are seen as key strategies for the more efficient use of land and water in Central Asia by the International Center for Agricultural Research in the Dry Areas (ICARDA), which is based in Syria but had a mandate for agricultural development in Central Asia (Karajeh, 2002). Sustainable increases in crop production will also support the economic development of the country. It is important to recognise that margin-

al land should be returned to native pasture to promote the enhancement of biodiversity; this is currently practised in Canada.

Dryland Management Systems

Conservation-tillage, which has been practised for the last three decades in Canada, could provide conditions to rehabilitate the land resources and provide support for sustainable soil use and management. The five priorities for agronomy and natural resource management research in spring wheat areas in Kazakhstan are moisture conservation, increase organic matter in the soil, soil fertility, residue management, and rehabilitation of the degraded lands.

Classical tillage practices using heavy machinery encourages soil erosion and causes loss of soil organic matter (Tebrügge, 2000; Reicosky, 2000). Intensive tillage practices in Eurasian grain farming region have reduced soil fertility and consequently crop production substantially (Suleimenov, 2000). No-tillage or conservation tillage represents the most dramatic change in soil management in the modern history of agriculture (Bradford and Peterson, 2000). This technique has great economic potential and crop production can be achieved with minimal erosion risk (Reicosky, 2000). Many years of collaborative research by the Consultative Group for International Agricultural Research (CGIAR) has demonstrated numerous benefits arising from conservation tillage.

With conservation tillage the notable reduction in costs to farmers can be as much as 30% compared to conventional tillage practices. The system was introduced in North America and is now widely used in South America, Australia, and, to lesser extent, in Europe (Reicosky et al., 1995; Grant, 1997; Lal et al., 1999). Two international centres e.g., Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) as well as ICARDA have active programs in Central Asia, including Kazakhstan. Activities in the region need to be considered, and also co-operation with these institutions is desirable.

Agroforestry system has emerged in the 1980s, i.e., a combination of fast-growing trees combined with agriculture in a system that also includes feed to support livestock. Agroforestry also provides a habitat for biodiversity and produces goods and services; in addition, it substantially increases carbon sequestration (Bruce et al., 1999). This technology can also provide conditions to conserve soil and rehabilitate degraded land that could support the economy in Kazakhstan. Together with conservation tillage, application of these technologies may have global implications for reduced carbon in the atmosphere, and thus global warming. This is yet to be demonstrated by field trials. A small change in the rate of carbon sequestered in dryland regions can have relatively large impact on atmospheric carbon dioxide. Over 1 billion people currently live in degradation-susceptible drylands and any effort to restore productivity in sub eco-regions

will be of benefit for their inhabitants (UNEP/ FAO, 1997). This is also true for Kazakhstan.

One of the fundamental arguments is that soil organic matter is lost in the topsoil, due to intensive agricultural practices, e.g., about 50% in North America (Lal et al., 1999). Uncultivated soils were in equilibrium with the native vegetation and accumulated large soil organic carbon reserves; however, cultivation disrupted the natural steady-state equilibrium. The carbon lost through the mineralization of organic matter can potentially be returned to the soil; with good management practices, it may be possible to exceed the original native organic matter content of many soils. Reduced grain prices in the last 15 years have forced Canadian farmers to diversify agriculture and test new crops in the prairies, i.e., canola (*Brassica Spp*), chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), and pigeonpea (*Cajanus cajan*).

Research around the world has proven that *soil fertility and organic matter is declining due to long-term use of conventional tillage techniques* (Putterbaugh, 1993; Acton and Gregorich, 1995). The loss of soil fertility and organic matter are the two major factors that cause the reduction of soil quality. Commercial fertilizers can be applied to correct the soil fertility, but this does not directly influence the soil organic matter. Loss of organic matter adversely affects soil erosion, and increased erosion is likely to will cause further decline of soil fertility and overall soil quality (Lal, 2001; Lal et al., 2001). Low fertility leads to lower biomass, production contributing to faster decomposition of soil organic matter.

It has been reported that introduction of heavy machinery has caused soil compaction in large areas and has contributed further to the decline of soil quality (Bradford and Peterson, 2000). Estimates of economic losses through soil compaction for the Eurasian Steppes differ, but appear to be significant (Nazarenko, 1993; Libert, 1995). In light-textured soils, the loss of organic matter also accelerates surface crusting, which reduces plant germination and, in some cases, total loss of the crop. There is a need to consider the loss of soil biodiversity as part of the soil degradation processes. In comparison to the world average, economic losses in grain production are so large that Kazakhstan can no longer afford to neglect this reality.

Conservation farming practices that encourage organic matter input in to the soil in Canada (Acton and Gregorich, 1995) include: using permanent crop covers (this is very essential), growing crops that contribute large amounts of organic matter (such as those with larger fibrous roots), adding manure and other organic amendments to the soil, and keeping the crop robust and productive by adequate fertilization. On-farm experimental research is needed in different eco-regions of Kazakhstan as well as the Eurasian countries to identify the cost effective technological options that enhance sustainable productivity. There is need to promote establishment of the government and private extension and consultancy services.

Irrigated Agriculture

Irrigated agriculture is very important for crop production in the Republic of Kazakhstan (Mukhamedjanov and Musekenov, 2002). Before independence, about 20 to 30% of crop was produced on irrigated land. On average, surface waters accounts for about 100 billion m³ year⁻¹. In dry years, it may be 50 billion of m³ year⁻¹. The total area used for irrigation is about 2.3 m ha, but during the last few years it has been significantly reduced. This is due to the difference between water demand and natural water resources availability. According to Mukhamedjanov (2002), water in dryland plays a significant role, not only in agricultural production but also in the stability of environmental and socio-economic sustainability.

Kazakhstan has not yet reached a level of optimizing the land and water resources use for agriculture in its dryland agriculture system. Imbalances between supply and demand cause degradation of land and environment. The real threat is in the lower reaches of the rivers and terminal reservoirs where ecological changes are irreversible. The technical level of many irrigation systems in Kazakhstan does not meet modern requirements. Kazakhstan needs to construct small dams to capture surface waters and water supply systems. Full-scale scientific research is needed to achieve sustainable use of water resources. International cooperation will likely help to speed up the process.

CONCLUSIONS

Considering its geo-political position, the Central Asia regions have attracted much attention after the fall of the Soviet Union and break-up the communal and command economy. Given its vast area and rich soils, Kazakhstan has addressed the issue of developing its agriculture. As part of the renewal strategy, the Kazak Research Institute of Grain Farming organised its first International Symposium on "Conservation Tillage Practices for Semi-Arid Regions" in 1992 in Shortandy, near Asatana. The second one, organized by FAO, CYMMYT, and ICARDA in September 1999, was more focused on conservation tillage. This meeting was the first one that brought together experts from the regions and from around the world, to identify the gaps and needs to develop national conservation tillage action plans leading to sustainable agriculture.

The five priorities for agronomy and natural resource management in Kazakhstan are: *moisture conservation, increased organic matter in the soil, soil fertility, residue management, and rehabilitation of the degraded lands*. A common perspective and understanding of conservation tillage is germane to the success of the crop production, specifically in arid and semi-arid regions of the world. To improve efficiency and achieve profitability in agriculture in

Eurasia, conservation tillage farming systems, which were developed in North America, can be an alternative to the existing technologies in the region. Crop diversification, which successfully achieved in North America, could make the agriculture a very successful business in Kazakhstan. The country has to improve also its water use and irrigated agriculture.

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Developments in Tillage and Cropping Systems in Central Asia

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ABSTRACT

Dryland agriculture is widely practised in most of Kazakhstan, while major crop production systems in the rest of Central Asia are based on irrigation. Development of improved soil conservation tillage practices is a challenge for dryland agriculture in the northern Kazakhstan, while in the rest of the region this type of tillage was never practised. Wheat is main crop on drylands, while wheat and cotton are the two strategic crops under irrigation. Crop diversification is needed in all parts of the region for better farmers' incomes and for sustainable agriculture.

The set of field experiments conducted by scientists from the national agricultural system in collaboration with ICARDA allowed us to conclude that number of conservation tillage operations can be significantly reduced in the northern Kazakhstan, while conservation tillage can be successfully introduced in both dryland and irrigated agriculture of Central Asia. Studies in northern Kazakhstan allowed us to conclude that there is no justification for summer fallowing once in four-five years, which is recommended practice. Many alternative crops are more profitable as compared to continuous wheat in all parts of Central Asia both on dryland and under irrigation.

INTRODUCTION

Central Asia includes three major climatic zones. The northern Kazakhstan steppes with a pronounced continental climate are characterized by very long and

cold winters and short, dry and hot summers. Spring wheat is the main crop grown in large rainfed areas in rotation with summer fallow practised once in three to five years. The southern parts of Central Asia, including Uzbekistan, Tajikistan and Turkmenistan, belong to the northern dry sub-tropics, and are characterized by rather cool winters and very dry and hot summers. In this area, until recently, cotton was the main crop grown under irrigation in rotation with alfalfa, with the latter now replaced by winter wheat. The middle section of the region occupied by Kyrgyzstan and southern Kazakhstan is climatically closer to the south of Central Asia with relatively lower temperatures throughout the year. Winter wheat is the main crop grown both under irrigation and rainfed conditions.

Conservation agriculture has been a generally adopted practice in northern Kazakhstan since the 1960s. Conservation tillage methods were developed by scientists of the Scientific Production Center of Grain Farming at Shortandy. The main advantages of conservation tillage were control of wind erosion and better water use efficiency (Barayev, 1978). The latter was achieved thanks to the stubble of grain crops left on the soil surface following conservation tillage. The stubble served to trap snow falling down during the long winter which otherwise would have been blown off by strong winds and drifted elsewhere. Due to the snow being accumulated by the stubble and additional snow ridging done with special snowplows, the water storage by the time of sowing of spring crops is significantly higher compared with that stored following moldboard plowing. These results in grain yield increases after soil conservation tillage when compared with moldboard plowing in numerous field experiments carried out in northern Kazakhstan (Barayev, 1978).

In northern Kazakhstan, primary tillage has normally been practised in the fall (Sept.-Oct.) after the harvest of small grains. On light-textured soils, conservation tillage has been done with equipment known as Noble blades (Jackson et al., 1983) to a depth of 12-14 cm, whereas for deep conservation tillage to 22-25 cm, the same type of equipment, known as sweep plows (Johnson et al., 1983) is used to insure better intake of snowmelt water in spring. In northern Kazakhstan, on all soil types, conventional tillage with moldboard plows was replaced with conservation tillage in the 1960s. The main objective of the study at Shortandy was to investigate the possibility of reducing the depth of fall tillage operations on heavy-textured soils.

In southern Kazakhstan, recommendations on soil tillage in the fallow-grains rotations include deep (20-22 cm) and shallow (12-14 cm) conservation tillage. Moldboard plowing is also practised to control weed infestation. The conservation tillage did not show a yield increase in the South (Kireyev, 1996). In the rest of Central Asia, the concept of conservation tillage was considered uninteresting for irrigated agriculture and was almost unknown in rainfed agriculture. Deep plow-

ing was a generally adopted practice, and tillage research was directed towards even deeper tillage combined with high rates of fertilizers. Thus, the objective of studies in these regions was to introduce some soil conservation tillage methods to assess the feasibility of these practices in both irrigated and rain-fed agriculture.

Wheat Production

Wheat production in dryland areas in northern Kazakhstan started on a large scale only during the 1950s, when 25 million hectares of grassland were plowed up for wheat. The rotation of spring wheat with summer fallow, which occupied 20-25% of the cropland, was a generally adopted practice (Barayev, 1978). It was mostly based on Canadian farming practices in Saskatchewan where soil and climatic conditions are very similar to that of northern Kazakhstan. This cropping system was established in the 1960s and has never changed. The only changes in the system occurred in the frequency of the fallow. For example, on Chernozem soils it was later recommended to introduce a fallow more frequently, once in 6 instead of 5 years to produce more grain (Barayev, 1988). The rotation recommended was "fallow-wheat-wheat-oats-wheat-barley". In this crop rotation only half of the cropland was allocated to spring wheat, another half was occupied with the feed grains oats and barley (33%) and the rest was fallow (17%). This was acceptable in the Soviet production system when State farms had plans to produce and deliver to the State a certain amount of grain in bulk, food and feed grains put together.

During the years after Independence, and with the liberalization of the economy, many changes happened in the structure of 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. Actually, producers abandoned half of the earlier sown marginal cropland. They stopped growing annual forages, i.e., annual grasses and maize for silage, because of an almost complete stop in large-scale livestock production. The area under perennial forages was reduced by half. The same took place with planting of feed grains barley and oats. The wheat grown area was also reduced by 23%. Subsequently, this wheat share in the sown area went up to 65% and barley's share went down to 10%. Perennial forages now cover 13% of the sown area, but this area usually is not part of the rotation system and is widespread on sandy soils to prevent soil erosion.

Thus, wheat covers now around 80% and barley around 13% of the sown area. In the north of Kazakhstan, small grains in fact occupy almost all of the sown area. Besides, some cropland area is under summer fallow, but present statistics do not capture this information as it is pooled together with abandoned weedy fallow. Since there is no direct administrative pressure on the decision-making of

producers, there is range of practices falling between a fallow share in the rotation of up to 33% and continuous grain cropping with no fallow. Most farmers are more likely to practice continuous cropping because they lack resources to do fallow management adequately (timely tillage to control weeds).

Crop Rotations

At the same time, there are no changes in the scientific recommendations related to crop rotations and the old ones are still in place. Summer fallow was justified on the concept of accumulating moisture and to control weeds. The first paper opposing the obligatory practice of summer fallowing (Suleimenov, 1988). It was never accepted as a possible alternative. This is why in this publication we analyze 3 year's data from a comparative study of crop rotations with an attempt to eliminate summer fallow from the rotations with the aim to diversify cropping practices. A reduction in area under summer fallow will overcome the soil erosion hazard because, in Kazakhstan after adoption of soil conservation tillage, the period of greatest danger in terms of soil erosion is the summer fallow. Of course, soil erosion could also be controlled through chemical fallow or strip cropping, but in reality, these technologies are not in place, because of socioeconomic conditions of farms.

In dryland agriculture of southern Kazakhstan and Kyrgyzstan, the generally adopted crop rotations consisted of summer fallow followed by grain crops for 2-3 years. Winter wheat was sown into the fallow or stubble. More common was continuous planting of barley on the stubble land. In irrigated agriculture of southern Kazakhstan and Kyrgyzstan, the cropland, by and large, has been allocated to winter wheat. The second crop is barley. Small areas are being occupied by sugar beet and maize, the latter both for grain and for silage. The dominance of wheat was justified by the old system, placing maximum grain output as the country's top priority. But presently, both countries are going through the transition process to a market-oriented economy and most land now belongs to private farmers or groups of farmers. In our study in Kyrgyzstan, we tried to identify opportunities for introduction of more alternative crops to improve farmers' incomes and sustainability of the production system.

MATERIALS AND METHODS

The Shortandy site in northern Kazakhstan is located in the semiarid steppe on a Chernozem soil, a heavy clay loam with the following characteristics of the arable layer: humus content, 3.5%, total N, 0.3%, bulk density, 1.15 g/cm³. The annual average precipitation is 350 mm with a maximum in July and one third of the precipitation is snow. The annual average air temperature is 1.20C. The tillage

experiment at Shortandy included three primary fall tillage treatments: deep, shallow and zero. They were studied under three fertilization treatments: 0, 20 kg P ha⁻¹, and 40 kg of N ha⁻¹ plus 20 kg of P ha⁻¹. These treatments were applied in the rotation fallow-three year continuous wheat.

The tillage experiments in rainfed region of southern Kazakhstan, Almalybak, were conducted on light Chestnut soils, a heavy clay loam with the following characteristics of the arable layer: organic matter content, 2.4%; total N, 0.3%; bulk density, 1.15 g cm⁻³. The annual average precipitation is around 350 mm and the average annual air temperature is 7.5°C. Zero, shallow and deep conservation tillage in the fall was compared to moldboard plowing of the stubble land. The tillage treatments were compared in a three year rotation: fallow-wheat-wheat.

In irrigated agriculture of Uzbekistan, soil tillage studies were conducted at the Akkovok site on typical Sierozems, i.e., heavy loams with the following characteristics of the arable layer: organic matter content 0.92%; total N, 0.13%; bulk density 1.37gcm⁻³. The annual precipitation is 350 mm with a maximum during late fall and early spring. The annual average air temperature is 12°C. Different depths of tillage were tested before planting of winter wheat after cotton. The treatments were the following: plowing with a moldboard plow to 20-22 cm, rotor cultivator to 10-12 cm with sub-soiling, broadcasting into growing cotton stand using shallow cultivation, 3-4 cm deep. In 2002, direct drilling into the cotton stand was tested using a cultivator-drill manufactured in Kazakhstan.

Studies on crop rotations in northern Kazakhstan were conducted at the Shortandy site during 2000-2002. The widespread crop rotation "fallow-wheat-wheat-barley" was taken as the control. This long-term experiment was run since 1965, with all four phases in place. Since 1996, the first field of the rotation fallow was split to three alternatives: fallow, oats, and dry pea. It took 3 more years to establish three crop rotations with the four fields in each. Thus, since 1999 each year we had three four field crop rotations and could collect data from all four fields of the rotations in each consecutive year. In this paper we have presented the data of the last 3 years.

Studies on crop rotation in southeastern Kazakhstan were conducted during 2001-2002 under arid and semiarid conditions. The average annual precipitation in arid zone was 220 mm and in semiarid 350 mm. In the arid zone, a comparative study of eight crops was conducted during two years following fallow land and one year following stubble land. In the semiarid zone, nine crops were tested and sown on stubble land.

The Zhany pahta site in Kyrgyzstan is located in the semiarid steppe. The annual average precipitation is 300 mm, and the average annual temperature is 8.5°C. Crop rotation studies included growing winter wheat after fallow as compared to growing it after field pea and safflower. Crop rotations were studied

with 60 kg ha⁻¹ P applied before fallow or crops replacing fallow, while 45 kg N was applied to the wheat directly. Two more treatments of improved fallow were studied: with manure applied at the rate of 30 t ha⁻¹ or with straw of the harvested crop applied to the fallow.

The study of crop rotations in irrigated agriculture was conducted in Kyrgyzstan. In a 3-year crop rotation, one field was occupied by row crops, maize and sugar beet. Both row crops were followed by barley, dry pea and safflower. The third field was sown with winter wheat in a common Sierozem heavy clay loam with the following characteristics of the arable layer: organic matter content, 1.63%; total N 0.095, total P, 0.09%; total K, 1.65%., pH 8.5. The fertilization rates used were the following: 30 kg N ha⁻¹ for dry pea, 60 kg N ha⁻¹ for small grains and safflower, 90 kg N ha⁻¹, 60 kg P ha⁻¹ and 60 kg K ha⁻¹ for sugar beet and maize. Average annual precipitation rate is 434 mm with maximum rainfalls in spring and early summer. Annual average air temperature is 10.8°C with hot summers but cool autumns. The year 2000 was drier than average and 2002 was rainy well above average.

The field experiments were laid out in four replications and the yield data were statistically analyzed. The data was collected on soil bulk density in the arable layer, soil moisture content in the top I-m layer, content of nitrate - N and phosphate, and weed infestation.

RESULTS

Soil Tillage

Rainfed Agriculture

In previous research on conservation tillage in the fall at Shortandy, deep tillage improved soil permeability, facilitating water intake in spring during the thawing of snow. Normally, snow falls and is blown from the fields by winds after moldboard plowing. If soil is cultivated with conservation tillage machines, the snow may be trapped by the stubble up to the height of the stubble (12-15 cm). Over a period of years, experiments were conducted that included a comparison of conservation tillage methods combined with fertilizer application in order to see possible interaction between tillage and fertilizer application (Table 1).

Table 1. Spring wheat grain yield as affected by soil tillage, fertilizer and preceding crop in northern Kazakhstan, average for 2000-2002.

Fall Soil Tillage	Fertilizer, kg ha ⁻¹			
	0	P ₂₀	N ₄₅ P ₂₀	Average
	-----t ha ⁻¹ -----			
On Fallow				
Deep	2.04	2.10	2.11	2.08
Reduced	2.27	2.30	2.29	2.29
Zero	2.11	2.23	2.31	2.22
Average	2.14	2.21	2.24	2.20
LSD _{5½} = 0.11 t ha ⁻¹				
On Stubble				
Deep	2.08	2.14	2.18	2.10
Reduced	2.12	2.12	2.30	2.18
Zero	2.02	2.30	2.46	2.26
Average	2.07	2.19	2.31	2.18
LSD _{5½} = 0.19 t ha ⁻¹				

Reduced or shallow tillage was observed to be the best irrespective of fertilizer application, but zero tillage gave the same yield as reduced tillage with application of nitrogen. *This clearly indicates that minimum or zero tillage may have an advantage, provided proper nitrogen availability is insured.* Following the fallow, the P fertilizer influenced the grain yield only in one year out of three, which is in contrast to previous findings indicating a significant positive effect of P on grain yield (Barayev, 1978). This might be due to the carry over of P applied on the field during many years before the experiment. Application of P fertilizers during the fallow period at the rate of 60-80 kg ha⁻¹ for 3-4 years of continuous grains is generally adopted practice. There was no response to N following the fallow, which indicates that on fallow there was enough N available. As to the tillage treatments, the deep tillage proved to be lower yielding with a slight difference between shallow and zero tillage.

On the stubble land, both N and P fertilizers increased yield by 6% when P was applied, and by 12% from NP fertilizer. As it was noted on the fallow part of the trial, tillage methods significantly affected the wheat grain yield on the stubble. However, there was an interaction between fertilizer and tillage. Zero tillage had no advantage over both shallow and deep tillage without fertilizer. The advantage of zero tillage was observed only with P fertilizer applied and further increased with the application of N fertilizer. It can be seen from the following

comparison. In previous, research done before it was found that deeper soil loosening causes a build-up of available nitrate N in the soil due to mineralization (Chmil, 1996). In southeastern Kazakhstan, the importance of tillage method is not so profound. In most cases, crop yields are the same for plowing and conservation tillage performed to the same depth (Table 2).

Table 2. Barley and proso grain yield as affected by primary soil tillage in the rainfed semiarid area, southeastern Kazakhstan.

Tillage Method, Depth	Barley			Proso (millet)		
	2001	2002	Mean	2001	2002	Mean
	-----t ha ⁻¹ -----					
Plow (20-22)	0.85	1.56	1.21	0.97	1.41	1.19
Conservation (20-22)	0.85	1.79	1.32	1.04	1.11	1.08
Conservation (10-12)	0.68	1.69	1.19	1.04	1.16	1.1
No primary tillage	0.59	1.29	0.94	0.92	1.14	1.03
LSD ₀₅ , t ha ⁻¹	0,16	0.25		0.34	0.26	

The reduced tillage depth led to lower crop yields, while the lowest grain yield was obtained in the no tillage treatment. The yield reduction under shallow tillage and no tillage might be explained by lower N availability and heavier weed infestation as compared to deep tillage. On average for 2 years, the number of weeds on the deep and shallow conservation tillage fields and on no-tillage as compared to plowing amounted to 114%, 122% and 140%, respectively. As to soil moisture, conservation tillage had some advantage in spring, but this difference disappeared later in the season. The no-till also increased the bulk density in the topsoil compared to conservation tillage i.e., 1.41 vs 1.29 g cm⁻³, which is seen as a disadvantage for crop establishment.

Although conservation tillage did not show an advantage in terms of crop yield, it demonstrated many advantages in conservation of energy and labor resources. Fuel spent per ha for seedbed preparation and planting for plowing, conservation tillage and no-tillage treatments amounted to 37.8, 24.6 and 7.4 liters, respectively. Labor productivity (time spent to work a certain soil area) on conservation tillage and no-tillage compared to plowing amounted to 129% and 282%, respectively.

In Kyrgyzstan, the study of two conservation tillage depths was combined with crop rotations and fertilization. Soil tillage was done to 12-15 cm and 25-27 cm in the fall before sowing. After planting of winter wheat in the fall of 2001, soil moisture was a little higher after shallow tillage: 12.8% vs. 12.0% because soil was loosened to a lesser depth. In spring, however, soil was moistened better when it was worked deeper: 17.1% and 19.0% for the shallow and deep conservation tillage, respectively. This was a major reason for the wheat grain yield increase on the deep-tilled soil by 9% as compared to the shallow tillage, on average, for the 2 years.

Irrigated Farming

Conservation tillage practices were widespread in the Soviet Union only in regions with prevailing dryland agriculture. Conservation tillage was adopted not only in the dry and semiarid steppe regions but partly in sub-humid areas as well. At the same time, conservation tillage was almost unknown in most of Central Asia where cotton was grown in rotations with alfalfa under irrigation. Studies in irrigated agriculture in Uzbekistan (Cotton Growing Research Institute) gave rather promising results, suggesting opportunities to reduce tillage operations (Table 3).

Table 3. Grain yield of winter wheat under irrigation planted after cotton as affected by seedbed preparation methods in Uzbekistan.

Seedbed Preparation	2001	2002	Mean
	-----t ha ⁻¹ -----		
Plow at 20-22 cm, harrowing and leveling in November	5.34	3.79	4.56
Rotor cultivation at 10-12 cm in November, with sub-soiling (45cm)	6.17	3.64	4.90
Broadcasting into growing cotton, shallow cultivation in October	4.89	4.09	4.49
Direct drilling into cotton stubble in November	-	3.71	-
LSD _{5%}	0.10	0.85	

In the dry year (2001) in the irrigated cotton-wheat system of Uzbekistan, a seedbed preparation with a rotary cultivator to 10-12 cm depth together with sub-soiling at 45 cm gave a higher yield of winter wheat compared to traditional deep moldboard plowing. In 2002, which was characterized by high rainfall and, because of this, with limited irrigation, grain yield was not high and not significantly different for the treatments. The observations indicated that, on average for two years, all method of seedbed preparation gave similar wheat yields as with

plowing at 20-22 cm. This shows that it is realistic to obtain comparable grain yields with much less cost of production under reduced tillage. For plowing, harrowing, leveling, and sowing, a total of 47 liters diesel per hectare is spent. For the minimum-tillage technology with just simple broadcasting using a cultivator, only 14 liters of fuel are spent. This is an important saving of resources not to mention that plowing is against soil conservation and a time consuming operation.

Crop Rotations

Rainfed Agriculture

Studies on crop rotations under dryland conditions were conducted in Shortandy, northern Kazakhstan to compare 4-year rotations. The standard crop rotation was a generally adopted rotation of summer fallow with 3 years of consecutive small grains: "summer fallow-wheat-wheat-barley". This was compared to continuous cropping when the summer fallow was replaced by oats or field pea. The yield data was collected during 3 years: 2000, 2001 and 2002.

All 3 years were relatively favorable as far as precipitation is concerned. The year 2000 was characterized by a very rainy period prior to sowing and before tillering of small grains and a very dry period between tillering and heading of wheat. The year 2001, on the contrary, featured dry and cool weather during the first part of the vegetation of spring wheat and a very rainy period from the jointing stage till grain filling, causing rather intensive development of plant diseases. During the vegetation period in 2002, rainfall was well above average accompanied with warm temperatures leading to higher than normal occurrence of plant diseases.

On average for 3 years and during each year, the grain yield was affected by placement of wheat after fallow or other preceding crops (Table 4). The grain yield of spring wheat sown on summer fallow on average for 3 years was 2.07 t ha⁻¹, with an advantage of 20-25% as compared with the yield of wheat sown after oats (1.72 t ha⁻¹) and after dry pea (1.64 t ha⁻¹), respectively. The difference was observed to be higher in favor of fallow in more favorable years: as high as 27% in the favorable 2002 and only 5% in the relatively dry year 2000.

This was contrary to common conclusions that summer fallow shows much higher yield advantage in dry years. It can be explained by the fact that the crop year 2000 was distinguished by very rainy weather prior to sowing and during the establishment of the spring wheat crop causing the equal water storage in the crops after fallow and on the stubble. The advantage of fallow against stubble land in available moisture storage by the time of sowing spring wheat during two years amounted to 20-30 mm in 1-m layer, whereas in 2001 it was even 20 mm higher on stubble land. The yield of wheat when sown after wheat as compared to wheat sown after oats or dry pea had no significant difference.

Table 4. Grain yield of crops as affected by crop rotations in northern Kazakhstan.

Preceding crop	Crop	2000	2001	2002	Mean
-----t ha ⁻¹ -----					
<i>Fallow-wheat-wheat-barley</i>					
Fallow	Wheat	1.32	2.18	2.70	2.07
Wheat	Wheat	1.26	1.76	2.12	1.71
Wheat	Barley	2.15	3.09	2.63	2.62
<i>Oats-wheat-wheat-barley</i>					
Barley	Oats	2.16	3.15	2.71	2.67
Oats	Wheat	1.09	1.75	2.32	1.72
Wheat	Wheat	1.10	1.48	1.87	1.48
Wheat	Barley	2.00	2.84	2.44	2.43
<i>Dry pea-wheat-wheat-barley</i>					
Barley	Dry pea	1.38	1.54	1.89	1.60
Dry pea	Wheat	1.14	1.74	2.03	1.64
Wheat	Wheat	0.94	1.32	2.25	1.50
Wheat	Barley	1.91	2.79	2.03	2.24
LSD _{5%}	0.26	0.23	0.19		

The yield of barley was higher than that of wheat by 65%. It was higher in the rotation with oats and fallow, but rather low in the rotation with dry pea, which indicates that in dryland conditions of northern Kazakhstan food legumes did not play a positive role when grown before small grains. Besides, one of negative factors associated with the dry pea was weed infestation, which was remarkably higher as compared to the rotation of small grains with the summer fallow or oats. The average weed density in the rotation with dry pea was substantially higher, especially of grass weeds, of which wild oats was the major representative.

The dry weight of weeds on average during three years was 9.9, 10.1, and 19.2 gm⁻² in the 3 crop rotations with fallow, oats, and dry pea respectively. It is important to emphasize that dry pea stand was not treated with chemicals, while small grains were sprayed by 2,4-D herbicide. Oats replacing fallow and leading to continuous cropping proved to be as high yielding as barley. Dry pea gave comparable grain yields as wheat. Thus, including oats and dry pea as replacement of summer fallow considerably increased the grain yield from total area including summer fallow (Table 5).

Table 5. Grain yield from total area of crop rotation as affected by replacement of fallow by crops in northern Kazakhstan.

Rotation	2000	2001	2002	Mean
-----t ha ⁻¹ -----				
Fallow-wheat-wheat-barley	1.18	1.74	1.86	1.59
Oats-wheat-wheat-barley	1.59	2.30	2.33	2.07
Dry pea-wheat-wheat-barley	1.34	1.85	2.05	1.75
LSD _{5%}	0.26	0.23	0.19	

In all 3 years, the grain yield from the total area including fallow was the lowest from the rotation "fallow-wheat-wheat-barley". The replacement of fallow with oats increased the grain production by 30% on average, with little difference between the 3 years. The replacement of fallow with dry pea increased the total production by 10%. Thus, both treatments with continuous cropping instead of rotation of small grains with summer fallow provided an increase in grain production from the cropland. Most important is the fact that the removal of the summer fallow from the cropping practice will contribute significantly to conservation of land, because the fallow practice is recognized as major source of soil erosion (Shiyatiy, 1996).

Studies in southeastern Kazakhstan conducted in the areas with arid and semi-arid rainfed conditions, showed that in the arid steppe crops failed on the stubble in the dry year (Table 6). The trial included sowing on stubble land because in the past most marginal lands were used for grain production. Apparently, in the arid dryland area there can be no other crop-growing practice than alternate summer fallow and crop. In dry years, crops can be obtained only following a fallow. Even then, many crops failed in the dry 2001 year.

Spring wheat produced 58% as compared with winter wheat. Spring wheat should not be recommended for this region. However, sometimes farmers grow spring wheat when for some reasons, they have some area left for planting in spring. Barley is a suitable crop for planting in spring, ensuring grain yields equal to winter wheat in a dry year and higher yields in favorable years. Oats provided grain yields less stable than barley, higher than barley in a wet year, and lower in a dry year. Proso was unsuitable for this region, just as was spring wheat.

Table 6. Comparative crop grain yields on fallow and stubble in arid rainfed area in southeastern Kazakhstan.

Crop	Fallow			Stubble
	2001	2002	Mean	2001
-----t ha ⁻¹ -----				
Winter wheat	0.63	1.79	1.21	0.33
Spring wheat	0.40	1.00	0.70	0.19
Spring barley	0.68	2.27	1.48	0.22
Oats	0.38	2.40	1.39	0.11
Millet (proso)	0.37	1.39	0.88	0.09
Lentil	0.29	0.89	0.59	0.08
Chickpea	0.32	0.99	0.65	0.13
Safflower	0.77	0.85	0.81	0.43
LSD _{5%}	0.11	0.35		0.06

Food legumes were low yielding (half the yield of winter wheat) like spring wheat, but they may compete, taking into consideration that market prices exceed the price of wheat by three-four times. Thus, if wheat prices are very low, food legumes can be good alternative crops replacing part of wheat-occupied area. Safflower as an oilseed crop may be another alternative with good potential. The yields of safflower are about 67% of those of wheat. In 2002, the wheat price went down while the safflower price went up, making this crop very promising for farmers. In the semiarid zone crop yields on the stubble land were more reliable (Table 7).

Table 7. Comparative grain yields in semiarid rainfed area in southeastern Kazakhstan.

Crop	2001	2002	Mean
	-----t ha ⁻¹ -----		
Winter wheat	-	2.87	-
Spring wheat	0.37	2.10	1.24
Spring barley	0.85	2.36	1.61
Oats	0.63	3.35	2.00
Proso (millet)	0.97	1.14	1.06
Chickpea	0.78	0.95	0.87
Grasspea	0.72	2.32	1.52
Lentil	-	0.77	-
Safflower	0.84	1.25	1.05
LSD _{5%}	0.28	0.35	

Many conclusions drawn for arid areas could be repeated in the area with more reliable rainfall, but only for crops grown on stubble land. Spring barley was a more reliable crop than spring wheat, especially in a dry year. Oats provided less stable yields compared to barley, being higher in wet year and lower in dry year. Proso failed and may not be recommended for growing in this region. Food legumes were lower yielding than winter wheat, but can be good alternatives under low-price scenarios for wheat. Grasspea demonstrated a rather high grain yield in a wet year.

In Kyrgyzstan, the generally adopted crop rotation in dryland farming is the practice of summer fallow followed by growing grains two-three years. In the experiment reported here there were three types of fallow with an attempt to improve it by application of manure or straw. Advocates of fallow recommend improving the fallow through application of manure or straw. The fallow treatments were tested against a replacement of the fallow by sowing of alternative crops (chickpea, dry pea and safflower). The most important advantage of the summer fallow is believed to be moisture accumulation. However, in both years, there was no significant difference between fallow treatments in soil moisture content in spring.

In the dry year, the application of manure did not improve moisture accumulation during the fallow. A standing crop reduced the soil moisture content, i.e., 12-14%. In a wet year, the application of manure played a positive role in moisture conservation (increase by 12%). The wheat grain yield was not significantly affected by improved fallow practices and was reduced by replacement of fallow by crop like safflower but not by dry pea (Table 8).

Table 8. Winter wheat grain yield on dryland as affected by summer fallow or preceding crops in Kyrgyzstan.

Fallow or preceding crop	No fertilizer			Fertilizer		
	2001	2002	Mean	2001	2002	Mean
-----t ha ⁻¹ -----						
Fallow	1.36	2.66	2.01	1.56	3.24	2.40
Fallow+manure	1.43	2.39	1.91	1.70	3.36	2.53
Fallow+straw	1.28	2.64	1.96	1.48	3.10	2.29
Dry pea	1.29	2.50	1.90	1.48	3.08	2.28
Safflower	0.93	2.19	1.56	1.14	2.51	1.82
LSD _{5%}	0.09	0.10		0.09	0.16	

Fallow management had no significant effect on wheat yield. Application of manure during the fallow period in addition to commercial fertilizer gave some positive result. Most important was the effect of dry pea as a replacement for summer fallow. It was very successful because the wheat yield was only slightly lower than after a summer fallow. At the same time, dry pea produced 1.34 t ha^{-1} of grain without fertilizer and 1.58 t ha^{-1} with fertilizer. Chickpea was tested only in 2002 and provided grain yield comparable to field pea. Safflower seems to be not the best preceding crop for winter wheat on dry land, reducing wheat yield by 24% as compared to fallow. The safflower crop produced 1.46 ha^{-1} of seeds without fertilizer and 1.95 t ha^{-1} with it, respectively, which definitely compensates for the reduction in wheat yield. And provide more economic benefits for the producers.

Economical assessment has demonstrated that the existing practice of fallow-wheat crop rotations is the worst possible treatment for farm profitability. Most important in this assessment are market prices, which are not in favor of wheat. During the harvest of 2002, market prices per ton for different crops were the following: wheat \$130; dry pea \$425; and, chickpea \$930. Because of this, the net profit from one hectare of wheat, dry pea, and chickpea amounted to \$87, \$717, and \$1355, respectively. Even if the chickpea price will be lower and farmer will be harvesting chickpea by hand, it will be much more profitable than wheat. With this level of difference in income in a favorable year, farmers can absorb losses in very dry years if chickpea fails. Remarkably, fertilizers were not profitable for wheat, reducing net profit per hectare from \$87 to \$27. Application of fertilizer for field pea and chickpea was found to be profitable, increasing net profit by \$28 and \$105 per ha, respectively.

Irrigated Agriculture

The study of crop rotations in irrigated agriculture was conducted in Kyrgyzstan. In a 3-year crop rotation, one field was occupied by row crops maize and sugar beet. Both row crops were followed by barley, dry pea and safflower. In the third field, winter wheat was sown. The yield of the three spring crops was affected by fertilizers, weather, and preceding crop, which were sugar beet and maize (Table 9).

Table 9. Grain yield of spring sown crops under irrigation as affected by preceding crops and with (+) and without (-) fertilizers in Kyrgyzstan, average for 2001-2002.

Crop	Sugar beet			Maize		
	-	+	Difference	-	+	Difference
	-----t ha ⁻¹ -----		--%--	-----t ha ⁻¹ -----		--%--
Barley	2.16	2.61	21	2.22	2.50	13
Dry pea	2.20	2.38	8	2.61	3.15	21
Safflower	1.88	2.31	23	1.93	2.36	22

LSD_{5%}: fertilization, 0.28; preceding crops, 0.52

An influence of preceding row crop was not noticeable for safflower and barley, but it became important for dry pea when mean grain yield of dry pea planted after maize increased by 26% as compared to sugar beet as preceding crop. The dry pea also out yielded safflower more remarkably, when sown after maize. The response of different crops to fertilizer was more or less similar. Winter wheat yield was affected by the preceding crops (Table 10). In both years, safflower was found the best preceding crop for winter wheat under irrigation. Winter wheat grain yield was higher when planted after safflower compared to wheat grown was 5% after barley and 13% after dry pea.

Table 10. Winter wheat grain yield under irrigation as influenced by preceding crops in Kyrgyzstan.

Crop	2001	2002	Mean
	-----t ha ⁻¹ -----		
Barley	3.09	2.91	3.00
Dry pea	2.91	2.63	2.77
Safflower	3.22	3.06	3.14
LSD _{5%}	0.30	0.33	-

Most important in this study was the fact that small grains, which are the most widespread crops under irrigation, proved to be the least economical. The net profit of wheat and barley amounted to only \$US 40-80 per hectare. Sugar beet was found the most profitable crop, giving net profit as high as US\$ 2,047, provided a proper infrastructure for this crop is in place. Maize and dry pea

proved to be very profitable crops as well insuring net profits of US\$ 1,380 and 1,098, respectively. Safflower also gave profits higher than wheat and barley (\$ 315 per ha). Of course, sugar beet and maize are labor consuming crops in Kyrgyzstan. This might limit the production scale, but no doubt that the area of production should increase. With implementation of mechanical harvesters of these crops common in developed countries, maize and sugar beet may have more definite advantage compared to small grains.

DISCUSSION

Adoption of soil conservation tillage started in northern Kazakhstan in the 1960s after studies conducted by the scientists of KGRI at Shortandy. Based on this data, two large plants were established in Astana to manufacture soil conservation equipment, including tillage machinery and stubble cultivator-drills. Soil conservation tillage and direct seeding machines were spread not only to all crop-land areas in northern Kazakhstan but also to western, eastern and central Kazakhstan, as well as to all steppe zones of Russia and the Ukraine, covering total area of over 40 Mn hectares.

The positive effect of this practice was found the highest in the steppes of northern Kazakhstan and adjacent steppe zones of western Siberia. It has been explained by some specific climatic features of these regions. Most important was the fact that an essential part of the annual precipitation constitutes snow, which otherwise was blown from the fields by strong winds. The conservation of standing stubble during sub-surface tillage allowed it to hold snow on the fields and thus substantially increase soil water storage by the time of planting of spring wheat, which is critical for obtaining reliable grain yields.

Conservation tillage not only enabled an increase in grain yields but also improved soil fertility management. According to observations during 15 years at Shortandy, deep conservation tillage reduced losses of organic matter (Zinchenko and Zinchenko, 1997), while minimal conservation tillage ensured an increase in humus organic matter content in the arable layer (Table 11).

Table 11. Loss of humus as affected by soil tillage after 15 years in northern Kazakhstan.

Tillage	Soil layer, cm				
	0-10	10-20	20-30	30-40	0-40
	-----%-----				
Moldboard plow, at 20-27 cm	7.0	7.0	10.5	10.8	8.5
Conventional tillage at, 20-27 cm	4.2	12.1	9.1	12.9	9.4
Conventional alternate, 12 and 25-27 cm	+6.1	2.5	2.9	6.2	1.1

In the Northern Great Plains of USA, tillage is not usually performed after harvest, because standing stubble holds snow on the field (Black, 1983). Tillage may be needed in some years when late summer and early fall precipitation has caused an abundance of weeds or volunteer cereal grain growth.

The summer fallow is a basic component of dryland farming. Summer fallow occupies a significant part of the cropland in dryland agriculture of many countries, including USA (Black and Bauer, 1983), Canada (Johnson, 1983), Turkey (Braun, 1999). Actually, in these countries the alternate wheat-fallow system is widespread. Some successful attempts were made to introduce alternative crops into crop rotations: rapeseed in Canada (Johnson, 1983), sorghum in USA (Jones and Johnson, 1983). With moderate application of N and P, yields for continuous wheat were found higher than for 2- or 3-year wheat-summer fallow programs on a Udic Boroll clay in, Saskatchewan (Johnson, 1983). By and large, summer fallow occupies at least 30% of cropland in the dryland farming systems of these countries.

The studies conducted in recent years at Shortandy and presented in this paper provide a basis for improvement of conservation tillage, aiming at further reduction of tillage intensity. One of the most important findings is the necessity to manage more adequately soil fertility while minimizing soil tillage. The no-tillage in the fall on heavy loam soils gave positive results provided N fertilizer was applied properly. This conclusion is very important because so far farmers in northern Kazakhstan did not apply N fertilizers for wheat growing. Small amounts of N were applied with fertilizers like ammonium phosphate. The reason is that most cropland soils in northern Kazakhstan were developed for grain production in the 1950s and they were rich enough in N till the 1990s. Therefore, more research should be conducted aiming at a better understanding of zero-tillage technologies for growing wheat with proper soil fertility management.

Conservation tillage in dryland agriculture of the southeastern Kazakhstan where winter wheat is the major crop is not being as widespread as in the north. It was recommended only in the cases of strong soil erosion. Our 2-year studies have led to conclusion that two methods of tillage with the moldboard plow and with the conservation equipment at the same depth gave the same grain yields. In the case of reduced tillage and of no-tillage in the fall the grain yields obtained were slightly lower because of higher weed infestation. However, energy savings and reduced labor costs occur with conservational tillage by companies with conventional tillage.

The same type of results was obtained during the studies in the south of Kazakhstan conducted in rain-fed conditions at the Krasniy Vodopad station for 2 years. In this region, rainfed winter wheat is a major crop. Spring barley also plays an important role, especially when winter wheat fails or was not planted in

the fall. In recent years, safflower as an oil seed crop became important and now occupies a significant area. The moldboard plow has remained the major tillage equipment in spite of many attempts to replace it with conservation tillage machinery. During 2 years of research, there was no obvious effect of tillage methods on crop yield on all three crops, with and without fertilizers. Soil tillage assessment depended on crop prices. Under low price scenarios, no-till treatment had an advantage over plowing. No-till beat plowing in all crops at any prices. No doubt, with higher prices for inputs this advantage will increase.

Studies in rainfed farming conditions of Uzbekistan demonstrated that the moldboard plow is still the best tillage equipment for winter wheat. The data showed the importance of plowing right after harvest of preceding wheat, followed by further shallow cultivation for seedbed preparation. No-tillage, however, was tried in 2002 and preliminary results were good: the grain yield obtained was equal to plowing. This indicates that further studies should be conducted with more adequate conservation tillage equipment and more efficient weed control under minimum tillage technologies, considering the input-use efficiency as well.

In irrigated agriculture, preliminary results reveal that there are opportunities of reducing the intensity of tillage. In the study in Uzbekistan during 2 years with different weather conditions, the results obtained were also very different. Under dry weather conditions, the rotary cultivator with simultaneous sub-soiling proved to be the best tillage treatment. During the very rainy year, when irrigation was hardly used, the best results were obtained with deep plowing and broadcasting under shallow cultivation. Based on this data, one can conclude that there are opportunities of reducing depth of tillage. Studies should be continued on zero-tillage involving more adequate equipment. Most important is the fact of considerably reduced cost of production when deep plowing was replaced by shallow cultivation. Actually, seedbed preparation and planting associated with deep plowing requires three times more fuel than shallow cultivation.

These findings are in accordance with results obtained in similar research in Turkmenistan. Difference in tillage depth resulted in different water infiltration rates, causing less water use for irrigation after reduced tillage (Suleimenov et al., 2001). Thus, shallow plowing, chiseling and disking resulted in less water used for irrigation compared with the deep plowing. On average, soil tillage at various depths (10-12 to 30-32 cm) before planting of winter wheat did not significantly affect grain yields. Today, a dramatic difference in cost of production means not much in Uzbekistan and next to nothing in Turkmenistan, because input prices are heavily subsidized. But a time will come, when market prices will be in place in these countries and then the importance of reduced tillage will become obvious. But, even under the present conditions, farmers can till their land with disks three times faster than with the plow, to plant crops earlier as needed.

Minimum tillage is gaining favor in Central Asia. In northern Kazakhstan, minimum tillage for spring wheat (no primary tillage and direct planting into stubble) was applied in 2002 on an area of around 10,000 ha. In southeastern Kazakhstan, minimum tillage was used on about 1,000 ha. In southern Kazakhstan, zero tillage was tested on 200 hectares. In Kyrgyzstan, conservation tillage was applied on an area of 50 ha. In Tajikistan, no-till broadcasting of wheat seeds into growing cotton was tried on about 2,000 ha. In Turkmenistan, replacement of plowing by disking for seedbed preparation prior to sowing of winter wheat was applied on area over 100 ha. In irrigated areas Uzbekistan, broadcasting of wheat seeds by cultivators into growing cotton was applied on area over 2,000 ha.

The crop rotation studies have provided new data for improved cropping systems. They have shown in northern Kazakhstan that crop production from total cropland can be increased. More importantly, they lead to a reduction in the area under summer fallow. This will have a positive environmental effect as summer fallow causes wind and water erosion. The recommendations of scientists justifying fallow usually recognized this danger, but recommended to practise strip-cropping. Actually, this recommendation was never carefully followed in the Soviet Union and completely stopped after the system of governmental control was replaced by private farming. Today it is a practice more like weedy fallow because farmers don't have the resources to cultivate fallow during the summer.

The experiment was laid out on rather small plots, where soil processes are observed purely with no interference of wind erosion, while large commercial farms in the region fallow standard at 400 hectares fields. According to Eskov (1996), 80-90% of soil organic matter losses in northern Kazakhstan are associated with soil erosion. According to Shiyatiy (1996), summer fallow fields erode most during snowmelt runoff. If soil losses from runoff on wheat stubble of southern Chernozem are equal to 1, then this coefficient after summer fallow would be 33 in the spring of 1983, he observed that intensive runoff of snowmelt on fallow caused rill erosion as deep as 10-20 cm and soil losses of 60 to 450 t ha⁻¹ in wash-out area. The conservation tillage using regular equipment for weed control during fallow destroys all wheat crop residues (1.5-2 t ha⁻¹) after three operations, whereas, at least four tillage, are done during the season.

In a number of studies in northern Kazakhstan and Siberia, soil nitrates were observed to leach during fallow to a depth of 3-5 m and deeper (Kiryushin, 1996). Summarizing studies in these two regions, the author concluded that more frequent summer fallow leads to greater N losses, especially under intensive mechanical soil tillage and insufficient P fertilizer. At Shortandy, organic matter losses were not substantial during 35 years and depended on frequency of fallow (Akhmetov et al., 1998). After 35 years, under wheat-fallow rotations with 50, 33

and 25% fallow, a loss of organic matter made 10%, 11% and 2% of original humus respectively, since 1962, when the organic matter content was 3.9%. Under six-field rotation (17% fallow) and under continuous wheat, no changes were observed at all. It should be noted that, conservation tillage in combination with straw spreading of the harvested crop was used during all years of the experiment.

The issue of reduction of area under summer fallow raised by Suleimenov (1988) 15 years ago has not been accepted by scientists of Kazakhstan in spite of 20 years' data supporting it. The abstracts of a recent conference in Astana, Kazakhstan, indicate that it was just one paper suggesting replacement of black fallow with cover crop fallow for forage production (Konopyanov, 2003). In other paper (Khabirov et al., 2003), it was stated that it was no difference in wheat yield obtained after black fallow and fallow with cover crops, oats and oats-pea, used for forage, but the authors made no conclusions based on this fact. The practice of summer fallow once in 4 years was advocated for so long that nobody wants to oppose it now. Many farmers do not use fallow but scientists still continue to recommend this practice.

Dvurechenskiy (2003) emphasized that summer fallow should occupy 25-33% of area under crop rotation. He and Viurkov (2003) once again recommended that summer fallow practice should include sowing of mustard strips 10-12 m apart in July to produce short barriers to trap snow drift during winter for improving water storage. This is not new; this kind of practice was recommended by Bakayev (1975) years ago. But it worked well only on small plots. When producers tried it at a large scale, it caused severe soil erosion by water, and was stopped.

The scientists of western Siberia working in steppe zone also are in favor of summer fallow once in 4-5 years (Moshchenko and Bormotov, 2000). However, Mr. V. Schnider (2002), a farmer recognized as the best in the region, showed that as distinct from other farmers of the region he practises continuous grain cropping: wheat (67%) and course grains, barley and oats (33%). Since establishment of the farm in 1994, the crop area increased from 1,500 ha to 21,000 ha by renting land from other less successful landowners. This farm is located at the border with the North Kazakhstan province, with average amount of precipitation 300 mm. The average grain yield on this farm for 1994-1998 and 1999-2001 amounted to 2.25 t ha⁻¹ and 1.87 t ha⁻¹, respectively, or 27% and 21% higher than average in the district following 12.2% of the cropland. One of reasons of his success was use of John Deer machinery, but the statement that he eliminated summer fallow in contrast to recommendations of scientists is remarkable.

Preliminary results on crop diversification in the dryland area of southern Kazakhstan and Kyrgyzstan indicate an opportunity for introducing alternative crops to small grains crops. Most important are safflower, chickpea, and field pea. In irrigated agriculture of Kyrgyzstan wheat, which is the crop occupying the

largest cropland area was found the least economical. In the experiments, the net profit obtained was largest from sugar beet and maize. Dry pea and safflower seem to be also good alternative crops to small grains. Certainly, in on-farm conditions results may differ as the markets for these products are limited. However, common beans already are spreading widely.

In irrigated agriculture in the warmer areas of Uzbekistan, Tajikistan, and Turkmenistan, where almost all cropland is occupied by strategic crops such as wheat and cotton, double-cropping after harvest of winter wheat is the only way to diversify agriculture. Mungbean, common bean, maize, buckwheat are suitable the crops for this purpose.

Certainly, all noted alternative crops will not replace wheat on large areas, but they may be used as good cash crops by small farmers. In addition, oilseeds like safflower and sugar beet may play important role in Kazakhstan as this country is importing edible oils and sugar. Food legumes in all countries should be more widely used as source of plant protein. So far, only Uzbekistan has a good internal market for grain legumes as they traditionally are used for food. There are no such diet traditions in Kazakhstan, but they may develop soon as poor people have no access to meat. Besides, Kazakhstan producers may think about exporting food legumes in future.

CONCLUSIONS

- Conservation tillage is a generally well-adopted practice in the rainfed farming of northern Kazakhstan. Three years' research findings show a possibility of minimum and zero tillage practices for growing spring wheat under adequate N fertilization.
- Conservation tillage in the rainfed agriculture of the middle part of Central Asia (southern Kazakhstan and Kyrgyzstan) gave yields comparable with plowing. More research is necessary for promoting widespread adoption of conservation tillage in this region.
- In the winter wheat systems under irrigation, there are real opportunities to replace traditional plowing by reduced tillage and even with zero-tillage. It will save large amounts of energy, conserve soil and its fertility by increasing soil organic matter content.
- Summer fallow is the generally adopted practice in dryland agriculture cropping systems throughout Central Asia. However, there are opportunities to reduce its area and replace it by grain or food legume crops. This will give more opportunities to farmers to increase incomes and will have great environmental effect for carbon sequestration in soil and reduced erosion.
- There are real opportunities in agriculture of southern Kazakhstan and in Kyrgyzstan to replace part of the wheat area by food legumes and safflower in dryland, and by beans, field pea, sugar beet and maize in irrigated agriculture.

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Improvement of Crop Productivity in Central Asia through Germplasm Enhancement

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ABSTRACT

Crop production in Central Asia has long history going back to 2000-3000 years BC. The farming in the past was mainly concentrated in irrigated areas along the two main river basins: Amu-Darya and Syr-Darya. The history of modern crop production in the region from 1900 to 2000 represents the competition between the two major crops: wheat and cotton. The former crop dominated until the beginning of 20th century. In the 1920s, and especially 1930s, cotton became a dominant crop to supply the USSR with needed fiber. The development of cotton varieties during this period reflected the needs of the industry, and at its first steps concentrated on yield and fiber quality.

The first breeding varieties (*Gossypium hirsutum*) were almost entirely based on selections from US varieties such as Acala. The progress in yield and quality reached by 1940s and 1950s was diminished by outbreak of diseases, e.g., *Verticillium dahlia*. New resistant varieties were developed based on introductions from Mexico. Overall cotton improvement in the region demonstrated continuous progress and satisfied the needs of the industry.

Wheat cultivation in Central Asia in the 20th century concentrated primarily in rainfed areas. The breeding work conducted at several stations in the region was initially based on local landraces and resulted in adapted varieties. However, the breeding work was not consistent and was interrupted. Since 1991, wheat became an important crop due to food security concerns and replaced cotton in some areas. The modern varieties developed in the region are well adapted and combine yield potential, grain quality and disease resistance. At the same time, a number of foreign varieties from Mexico, Russia, Turkey, USA and other countries are cultivated in the region.

INTRODUCTION

History of Farming in Central Asia.

The region comprises the countries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan with the overall population of almost 60 M people and arable land of 8 M ha, without northern Kazakhstan (Program Facilitation Unit, 2003). Agriculture of Central Asia has an ancient and interesting history, representing the dynamic changes in the farming systems, choice of crops and cultivation technologies as well as the utilization of water - the key element of crop production in the region. Central Asia is a home to numerous wild species of cereals.

During the Neolithic Era the tribes populating the foothills of Kopet Dag mountains on the territory of modern southern Turkmenistan started to domesticate *Hordeum spontaneum*, dominating wild cereal in the region (Masson, 1971). Around 7000 BC the tribes from northern Iran brought wheat to the region and started its cultivation under rainfed conditions in a narrow strip of land between the mountains and the Karakum Desert. The Geouksuk Oasis in the territory of modern Tedjen city, developed the first irrigation systems in the second part of the fourth Millennium BC. These tribes migrated East and South-East towards the Murgab and Zerafshan rivers, establishing new centers of crop cultivation, primarily wheat and barley. By the end of 2000 BC, irrigated farming was also established in fertile valleys such as Fergana, Gissar and along the rivers of Amu-Darya, Kashkadaria, Surhandaria, and Vakhsh (Andrianov, 1969). Some irrigation canals built at that time in the Fergana Valley are still used.

The other powerful invasion to the Region was during the Bronze Age by the nomadic tribes from the Northeast. These tribes were mainly involved in raising cattle. However, while migrating with the animals from the steppes in winter to the summer pastures in the mountains, they planted wheat under rainfed conditions at mountain foothills and collected the grain while migrating back in early fall. These tribes occupied the northern part of Central Asia up to the irrigated areas of Fergana and Gissar Valleys and main rivers. Cereals dominated in the region, providing an essential part of diet for the tribes (Udachin and Shakhmetov, 1984).

Thus, the irrigated and rainfed farming, established in Central Asia as early as 2000-3000 BC, expanded and diversified in the modern era. It witnessed the rise and fall of kingdoms, occupation of the region by neighboring tribes, and establishment of the modern nations, but essentially remained the same till the late 19th early 20th Century when modern agriculture started to develop.

The region grows a number of crops, and all of them are important. However, the current paper is devoted to two major crops of Central Asia: *cotton* and *winter*

wheat, with the objective to demonstrate the changes in crop productivity achieved through breeding. The paper does not cover the spring wheat in northern Kazakhstan which has a totally different environment, constraints and production system. A detailed review of wheat breeding for northern Kazakhstan and Siberia was done by Morgounov et al. (2001).

COTTON IMPROVEMENT IN CENTRAL ASIA

The archeological excavations conducted near Samarkand in 1933-34 found cotton fiber dated around 720 AC. According to Bartold (1924), the Arabs traveling in Central Asia in the 10th Century mention production of cotton fabric in Samarkand, Bukhara, Mary, Khoresm, and Tashkent. From the beginning of cotton culture in the region, the Asian species *Gossypium herbaceum* was cultivated. The Asian cotton varieties-populations cultivated till the end of the 19th Century were characterized by low yield, small ball and poor fiber quality.

The first attempt to replace local varieties was undertaken in 1871, when the Egyptian cotton *G. barbadense* was introduced and distributed to peasants near Tashkent. Due to late maturity of the new varieties, the crop failed. In 1883 the first *G. hirsutum* varieties from USA (King, Peterkin, Russel and others) were introduced to Fergana Valley, in 1907 to Khoresm oasis, and in 1910-12 to Zerafshan Valley. The new varieties were very successful with the yield advantage of 50-100% compared to local varieties and, by the beginning of the 20th Century already reached 200,000 ha (Straumal, 1974).

Overall cotton production in Central Asia was governed by the growing needs of the USSR in cotton fiber. Figure 1 shows area in Central Asia under wheat and cotton from 1913 to 2000 (Straumal, 1974; Anon, 1996; PFU, 2003). It is obvious that as industrialization of the USSR took place in the 1930s the area under cotton grew dramatically and became equal to wheat by 1940. Huge irrigation projects (Karakum Canal, Vakhsh Valley and others) were bringing more and more land into cultivation, which was occupied by cotton.

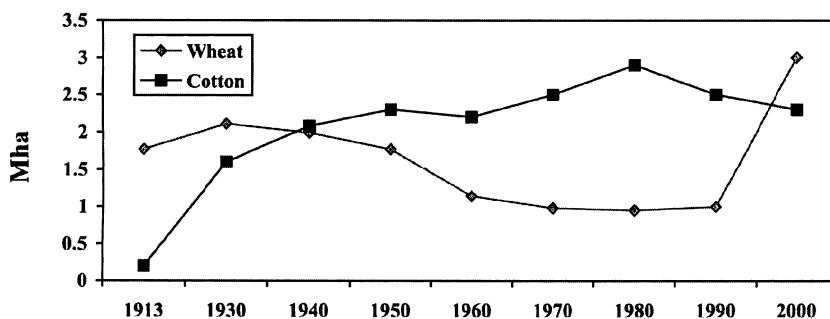


Fig. 1. Wheat and cotton area in Central Asia in 1913-2000.

By 1960, wheat was almost entirely removed from irrigated land in the region and cotton monoculture was established. The cotton area started to shrink in the 1980s, especially in the 1990s, as a result of breakup of the Soviet Union, economic crisis and disruption of the linkages with fiber processing industry in Russia and other states, resulting in a dramatic reduction in demand for cotton. At the same time, the newly independent states of Central Asia prioritized grain self-sufficiency and the wheat area occupied almost half of irrigated land in the region.

This change of cropping system, exemplified in the relative area of cotton and wheat in Central Asia, represents an important paradigm of land being so well used and so responsive to the needs of people whether it is provision of basic food or raw material to the processing industry. The people and land in Central Asia have tremendous resources.

Cotton breeding started in Central Asia in 1910-15 at several research stations in Tashkent, Andijan, Namangan and Fergana, and had six landmark changes of varieties with clear objectives and achievements (Straumal, 1974).

First

The first US cotton varieties so well adapted to the region were not maintained and eventually transformed into mixtures-populations that were maintained by the cotton cleaning factories, which also supplied the seeds to the farmers. By 1931 these mixtures were replaced by varieties Navrotskiy (selection from variety Russel), Navrotskiy Triumph (selection from variety Triumph), 169 (selection from Tashkent mixture), 182 (selection from Kok Chigit mixture) and others. These varieties increased cotton yield by 15-20%, fiber length by 1-2, mm, and fiber yield by 4-5%. Experiments with Egyptian cotton *G. barandense* started in several regions. A network of cotton breeding stations was established by 1931. The area under cotton increased from 0.1 M ha in 1921 to 0.59 M ha in 1925, and to 1.5 M ha in 1930, eventually reaching 2.1 M ha in 1931.

Second

The main objective was the increase of the fiber length and yield. By 1941 the varieties with the fiber length 31-31 mm occupied 72% of the area compared to about 1% in 1932. The main variety during this period was 8517, bred by S.S. Kanash at Turkestan Breeding Station near Tashkent, while selecting from the US variety Acala 0278. This variety was 3-4 days later compared to Navrotskiy, but had a longer fiber. However, this variety along with others popular varieties in the 1930s turned out to be highly susceptible to *Verticillium dahliae*. Varieties of *G. barbadense* reached an area of 0.2 M ha.

Third

Introduction of resistant varieties was the main objective during this period. Variety S-460, also bred by S.S. Kanash, was 3-4 times more resistant to *V. dahliae* compared to 8517. This variety was derived from a cross between variety 8517 (selection from Acala 0278) and 36M2 (selection from Acala 036). It was higher yielding (up to 5%) and had better fiber quality (up to 10%), but was 3-4 days later compared to 8517. The production suffered due to the fact that cotton frequently was not harvested in time and suffered from snowfall and rains. Cotton area dropped from 2.1 M ha in 1941 to 1.3 M ha in 1946.

Fourth (1947-1964).

The major variety during this period of time was 108F, which reached a unique area of 1.7 M ha in 1964. The variety was bred at Fergana Breeding Station and originated from a cross between US variety Cook and selection from Acala 036 - variety 36M2. Though it was similar in yield to S-460, its earlier maturity gave a considerable advantage. Variety 108F maintained resistance to *V. dahliae*, which was eventually overcome by the pathogen. Total cotton area stabilized at 2.2-2.3 M ha including 0.15 M ha of *G. barbadense*, which by 1964 was entirely represented by locally bred varieties.

Fifth (1965-1980).

Resistance to *V. dahliae* became the first priority due to large areas affected by the pathogen. New resistant varieties Tashkent 1, 2, 3 occupied the major area. These varieties were derived from a cross of semi-wild Mexican entry 06422 with local variety 4727. The F3 selection was crossed back to 4727. The resulting germplasm possessed resistance to diseases, high yield, and good fiber quality and became very popular in the region. The changes in fiber quality during the period of 1930-1970 are presented in Figure 2. Obviously, the production of longer fiber made tremendous increase and by 1970 fiber shorter than 30 mm was not produced at all.

Sixth (1981-1990).

Unlike previous years, there was no single major variety used in production during this period. The period was characterized by the diversification of the genetic base of the new varieties. The varieties like Ak-Bayat, S-6524, Bukhora 6, Ak Darya 6, Mekhrigon and others originated from diverse crosses, and combine resistance to diseases, high fiber yield and quality. The cotton yield of varieties released in 1980-2000 show a clear tendency toward higher yield potential of the newest varieties, e.g., from less than 3 t ha⁻¹ in 1961 to about 4 t ha⁻¹ in 2000.

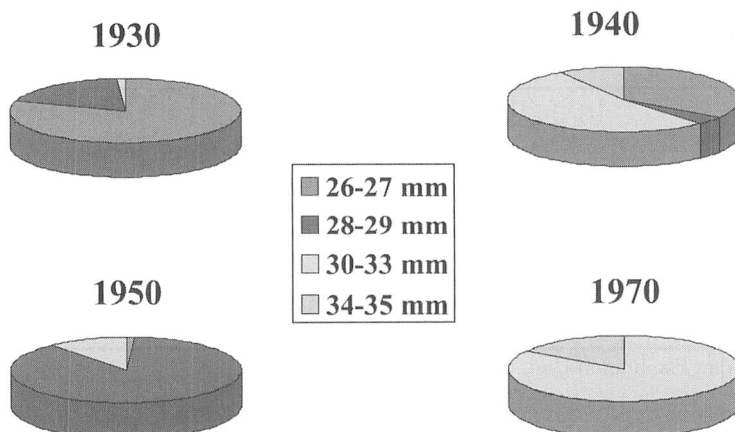


Fig. 2. Frequency of production (%) of cotton fiber of different length in Central Asia in 1930-1970 (Source: Straumal, 1974).

Summarizing 90 years of cotton breeding in Central Asia, the obvious conclusion is that the production system met the increased demand of high quality fiber from the Soviet Union industry. The first commercial varieties were based on selection from varieties from USA, which initially presented sufficient diversity for yield, fiber quality and disease resistance.

The monoculture of cotton resulted in severe disease epidemics which were addressed by development of resistant varieties based on wide crosses and diversification of the genetic base of modern varieties. Systematic efforts of cotton breeders in Central Asia resulted in spectacular progress in regard to both fiber yield and quality for both species cultivated in the region, e.g., *G. hirsutum* and *G. barbadense*.

WHEAT IMPROVEMENT IN CENTRAL ASIA

Recent production figures are listed in Table 1. The future perspectives for cotton breeding and production at large depend on the international market for cotton and the potential role of Central Asia. Even during the volatile 1990s the crop demonstrated its competitiveness, and for countries like Tajikistan and Uzbekistan proved to be one of the main sources of foreign exchange. The irrigated land given to wheat might be gradually taken back for expansion of cotton. The status of cotton breeding will depend on development of the sustainable outside markets for Central Asian cotton, which will then dictate the requirements for the fiber. So far, local processing of cotton into fabrics is not sufficiently developed. The cotton breeding programs in the region certainly benefited from closer international linkages established after 1991 and free germplasm exchange.

Table 1. Cotton area, yield and production in central Asia in 2000.

County	Area	Yield	Production
	-10 ³ ha-	-t ha ⁻¹ -	-M ha-
Kazakhstan	118	NA	NA
Kyrgyzstan	38	2.6	98.2
Tajikistan	239	1.4	335.4
Turkmenistan	621	NA	NA
Uzbekistan	1452	2.3	3200

(Source: Program Facilitation Unit, 2003).

The archeological excavations in the territory of Central Asia showed that though *Triticum compactum* and *T. durum* were cultivated during ancient times, *T. aestivum* or bread wheat, became the dominating crop from 500 BC to 500 AC (Yakubtsiner, 1956). Local varieties well adapted to the region dominated until the late 19th century when the region fell under Russia. The Russian government considered Central Asia as a cotton-producing region and, with the development of the railroads, it was easier to bring grain from Siberia or European Russia instead of producing it in the Region.

At the beginning of the 20th century, with the yield of irrigated wheat and cotton being 1 t ha⁻¹, the profitability of cotton was three times higher. However, by 1913, wheat was still a major crop occupying 49% of the land compared to 15% under cotton. The breakdown of wheat area (spring and fall planted, irrigated and rainfed) and yield in different regions of Central Asia in 1915 is given in Table 2. Interestingly, across Turkestan (name of Central Asia in the past) the share of rainfed spring wheat in total wheat area was 33%, followed by irrigated winter wheat or fall planted wheat (30%), irrigated spring wheat (27%) and rainfed fall planted wheat (10%). The highest yield was demonstrated by fall-planted irrigated wheat (0.89 t ha⁻¹). The yield of irrigated spring wheat was equal to rainfed fall-planted wheat, i.e., 0.73 t ha⁻¹. The productivity of rainfed spring wheat was lowest at 0.56 t ha⁻¹ (Udachin and Shakhmetov, 1984).

With the time the share of spring planted wheat reduced significantly and presently fall planted wheat is a major crop in the region (Fig 3). By 1930, wheat occupied approximately 1.5 M ha, including 75 % under irrigation. With more priority given to cotton, the area decreased by 1950s to less than 1 M ha, and only 30% of wheat was cultivated under irrigation (Udachin and Shakhmetov, 1984). Wheat regained its popularity in the 1990s when the newly independent states of Central Asia put forward the objective of self-sufficiency in grain. The current area of wheat is reaches 3 M ha. The changes in wheat area are shown in Figure 1.

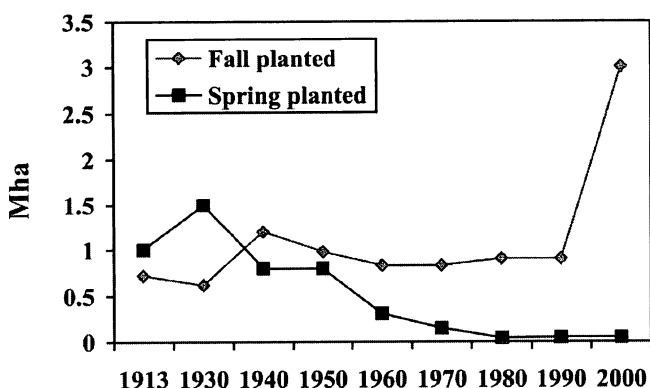


Fig. 3. Area under fall and spring planted wheat in Central Asia (without Northern Kazakhstan) in 1913-2000 (Source: Udachin and Shakhmetov, 1984).

The first systematic attempt to study the variability of wheat grown in the region was undertaken in 1909 by Turkestan Experimental Station, near Tashkent, which evaluated 300 entries collected in the region (Dorofeev, 1987). Most popular local landraces were Sary Magiz, Ala Biruk, Kzyl Bugday, Nar Kzyl, Ak Bugday. They represented native populations well adapted to the region with good drought and heat tolerance, tall, with fragile spikes.

The second group of varieties was represented by introductions from Russia and Ukraine brought by peasants and Kossaks who migrated to the region from European part and from Siberia. Varieties like Beloturka, Kubanka, Arnautka, Belokoloska and others adapted to the region provided more responsive type of germplasm compared to local populations.

Numerous wheat collections were conducted across the region, including the one by the famous N. Vavilov in 1916, who traveled from Tashkent to Pamir Mountains. The collections and expeditions covered the region very well. The description of wheat cultivation practices and varieties was published.

Uzbekistan

Wheat breeding in Uzbekistan started in 1924-25 with organization of the research stations (Dorofeev, 1987). Several stations were assigned the responsibility for wheat breeding: Kattakurgan, Djizak, Fergana, Tashkent, and Karshi. The first varieties naturally were derived from selections from the local landraces. The varieties identified and released in 1930s and 1940s were Greacum 117, 240, 128, 646, Erithrosperrum 5755, 811, 1910, 100, and others; these were higher yielding and well adapted to the region. At the same time, they did not respond to higher inputs and remained susceptible to diseases, primarily rusts.

The landmark varieties of this period were the spring wheat Kzyl Shark derived from Turkmen population and the winter wheat *Pseudomeridionale* 122 selected from Talas landrace. As wheat was moved almost entirely to rainfed conditions, the experimental station in Gallyaoral was transformed into the Uzbek Research Institute of Grain, taking responsibility for wheat research in Uzbekistan.

New varieties released in 1970s and 1980s from the Institute originated from crosses, e.g., Greacum 3 (Surkhan 5688/*Erithrosperrum* 841//*Greacum* 289), *Erithrosperrum* 100 (Kyrgyzskaya 3/*Greacum* 646), and *Tezpishar* (Bezostaya 1/*Greacum* 646). The Central Asian branch of the Vavilov Institute collected and evaluated wheat germplasm both from inside and outside of the country. The variety for irrigated conditions, Unumli Bugday, was released in 1983 and played an important role for irrigated wheat production in the 1990s.

Kyrgyzstan

Systematic wheat breeding in Kyrgyzstan started in 1934 at Frunze Agricultural Experimental Station, which was transformed to Kyrgyz Research Institute of Farming in 1956 (Udachin and Shakhmetov, 1984). Four years later, a breeding network was established, including research sites (Przhevalsk, Naryn, Norys, Uzgen) at major soil-climatic zones. During the first 5 years, the selections were made from 110 landraces, resulting in close to 5000 lines being screened.

However, the varieties from outside occupied up to 75% of the area in the country in 1940. The first local winter wheat variety *Erithrosperrum* 9 and spring wheat *Erithrosperrum* 14 and 41 were released in 1946-48 and were derived from those selections. These varieties and others replaced the old varieties and by 1954 were cultivated on the area of 220,000 ha or 74% of total crop. However, they did not satisfy producers due to lodging tolerance and susceptibility to rusts.

Wheat production in Kyrgyzstan was not subjected to such dramatic changes as in Uzbekistan due to the fact that cotton was cultivated only at a limited geographical area in the Southern part of the country. The tendency in Kyrgyzstan was intensification of wheat production, especially in irrigated and high rainfall areas. The old varieties were not suitable for higher fertilizer rates and consequently lodged.

The variety which successfully adapted to the higher inputs was Bezostaya 1 from Krasnodar Agricultural Research Institute in Russia. Bred by Academician P.P. Lukjanenko, this variety was and still is a masterpiece of breeding and covered millions of hectares in the USSR, Eastern Europe and Central Asia. Not only did it contribute to production but also was an extremely successful parent in development of new varieties. In regards to Central Asia, this variety is still grown and preferred by some farmers who maintain low input production.

In 1970-80s, several varieties were released which were derived from crosses with Bezostaya 1: Kirgizskaya 100, Intensivanaya, Erithrosperrum 80, Frunzenskaya 60. The facultative variety Intensivnaya demonstrated unique adaptation, being successfully grown at fall and spring planting. This, coupled with excellent bread-making quality, assured long life of this variety, which is still widely grown.

Turkmenistan

The work on wheat started in 1929 at an experimental field near Ashgabat, where it conducted evaluation of landraces grown in different regions of the country (Dorofeev, 1987). It was shown that wheats originating from mid-Amu-Darya Basin are all of winter habit, those from Murgab-Tedjen region are spring types, and the Ashgabat region group is represented by both types.

Wheat research was discontinued in 1930 and started again in 1937 with establishment of Turkmen Breeding Station. Several improved varieties were released in 1940s (Turtsicum 57, Meridionale 77, Turkmenskaya). However, in 1949, the breeding work was discontinued once again. It started in 1957 at Iolotan Breeding Station and later was transferred to Turkmen Research Institute of Farming. These changes in wheat breeding in Turkmenistan are a reflection of cotton being a major crop and wheat having little importance in the past. In the 1980s and 1990s, Bezostaya 1 and other varieties from outside were cultivated in the Republic.

Tajikistan

Wheat breeding started in 1931 at the Tajik Experimental Station, later transformed to Tajik Research Institute of Agriculture (Udachin and Shakhmetov, 1984). Due to its mountainous landscape, Tajakistan had very wide diversity of wheat grown at different environments and different altitudes. Experiments by N. Sukhobrus in 1932-35, with more than 9000 entries representing all types of wheat grown in Tajikistan, showed that local germplasm from lowlands was drought tolerant, but low-yielding. The germplasm from European Russia and Siberia was late and also low yielding. The local landrace Surkhak from Gissar and Kulyab, originating from latitudes of 700-1600 meters above sea-level (masl) was best adapted. The spring germplasm originating from the Garm region at altitudes of up to 2500 masl was well adapted for spring planting.

A number of selections from the landraces were released in the late 1930s and early 1940s, e.g., Surkhak 194, 5688, Irody 1006, and others. Variety Surkhak 5688 had very broad adaptation to rainfed conditions and was one of the leading varieties across Central Asia. Untill now, it is still cultivated in some areas with limited rainfall. In the 1970s, some Mexican wheats were tested for irrigated

conditions of Tajikistan and adapted very well. As a result, variety Siete Cerros was released and still cultivated on a small scale. Modern wheat varieties in Tajikistan like Navruz and Sharora derived from crosses and represented semi-dwarf types suitable for high input technologies.

Kazakhstan

The winter wheat has been cultivated for a long time on the foothills of the Tyan Shan mountains, mainly without irrigation but with sufficient rainfall. The strip of land along the mountains stretching from Tashkent to Shimkent, Taraz, Almaty, and Taldy Kurgan is planted to wheat with the total area of almost 1 M ha. The rainfall follows a Mediterranean pattern.

Breeding for this part of Central Asia started in 1923 by A.K. Golbek at the Red Fall Breeding Station (Udachin and Shakhmetov, 1984). He was one of the first breeders to collect and analyze wheat variability in Central Asia. Variety Pseudoturicum 2115, developed at this station by selection from a population from Samarkand region, was a major variety in the region in 1940s. Variety Red Star released in 1950 was also very successful. The more recent varieties Krasnovodopadskaya 25 and Yuzhnaya Zarya (both irrigated types) originated from crosses and are cultivated respectively in Turkmenistan and Southern Kyrgyzstan.

A very successful winter wheat breeding program is located at Kazakh Research Institute of Farming near Almaty. Both rainfed (Bogarnaya 56, Almaty polukarlik, Steklovidnaya 24, Karlygash) and irrigated (Progress, Zhetisu) types of wheat have been developed combining high yield potential and good bread-making quality. Most of them originated from crosses, with variety Bezostaya 1 once again showing the value of this variety for wheat breeding in Central Asia (Dorofeev, 1987). Spring wheat remains a minor crop in southern Kazakhstan.

WHEAT IN CENTRAL ASIA IN THE 1990's

With the breakup of the USSR and subsequent independence, wheat production in the region was highly prioritized and the area increased of the former republics, at the expense of cotton. The yearly rate of growth in wheat areas in the various countries of CA from 1988 to 2000 was: -6% (Kazakhstan), 7% (Kyrgyzstan), 9% (Tajikistan), 12% (Turkmenistan), and 8% (Uzbekistan). More attention given to wheat was also reflected in higher yields. The total wheat area and yield in Central Asia in 2000 are listed in Table 3.

The new research framework was established to address development of new wheat varieties and technologies for irrigated condition. In the case of Uzbekistan new Andijan research Institute of Grain and Legume Crops was established in

Fergana Valley in 1997-98 to lead and coordinate the development of new varieties. Few years later, the branches of this Institute were established in all the administrative regions of the country.

As the main centers, like Andijan and Gallyaoral, conduct the basic breeding activities the branches across the country are more involved in multi-locational testing of the advanced lines, seed production and development of technologies. Similarly, in Tajikistan, where only one institute was involved in wheat research, several experimental stations and sites were organized into a network of multilo- cational testing at different soil and climatic zones of the country.

The expansion of wheat in the 1990s required new varieties suitable for irriga-

Table 3. Wheat area, yield and production in Central Asia in 2001.

Country	Area	Yield	Production
	-10 ³ ha-	-t ha ⁻¹ -	-M t-
Kazakhstan ¹	10,826	1.2	12,910
Kyrgyzstan	478	2.5	1,190
Tajikistan	343	1.2	406
Turkmenistan	750	1.6	1,200
Uzbekistan	1,219	3.0	3,689

¹ including northern Kazakhstan; (Source: Program Facilitation Unit, 2003)

tion and higher inputs. With the exception of Kazakhstan, and partly Kyrgyzstan, the existing local varieties were not suitable for production due to low yield- potential, and susceptibility to diseases and lodging. Initially in the mid 1990s, varieties from Russia, and particularly from Krasnodar Agricultural Research Institute, played very important role. They covered almost the entire irrigated wheat area in Uzbekistan and substantial part areas Turkmenistan, and some in Kyrgyzstan and Tajikistan (GTZ-CIMMYT, 2003).

Varieties like Soratnitsa, Spartanka, Skiphyanka, Yuna provided high yield but were late and required up to 4-6 irrigations using the scarce water resources of Central Asia. They also turned out to be highly susceptible to yellow rust, which devastated them during the epidemic of 1999 and 2000. These varieties were replaced in the beginning of 2000 by newer varieties more resistant to diseases: Kupava, Knyazhana, Kroschka, Polovchanka and others. Interestingly, all these varieties maintain the type of Bezostaya 1, though shorter and more responsive to inputs.

The new winter wheat varieties developed in the 1990s by the national breed- ing programs were well adapted to the local environments, and importantly were earlier and required less water for irrigation (GTZ-CIMMYT, 2003).

Variety Almaly from Kazakhstan (6862-50431, Bulgaria x Bezostaya 1) is resistant to yellow rust with good bread-making quality. Released in 2002, it is highly demanded by farmers and has potential to become a major variety in south east Kazakhstan, replacing variety Steklovidnaya 24. Variety Naz, also released by Kazakh Research Institute of Farming for rainfed conditions of Kazakhstan and Kyrgyzstan, combines good tolerance to drought and resistance to yellow rust.

Recent varieties from Kyrgyz Research Institute of Farming (Bermet, Dostyk, Kyzyl Dan, Kyal, Tilek) were released for irrigated conditions and, while possessing very high yield potential, have variable disease resistance and grain quality. Uzbek varieties Gairat, Chillaki, Ulugbek 600, Yanbash combine earliness and good yield potential, providing competition to Russian varieties. Varieties Navruz and Sharora from Tajikistan, though very high yielding, lack resistance to yellow rust and have poor bread-making quality. Fig 4 illustrates the origin of the varieties officially released in the region and in selected countries. It is obvious that the germplasm originating from the region and from Russia dominates production, though some European varieties have been entering the list or recommended varieties as well.

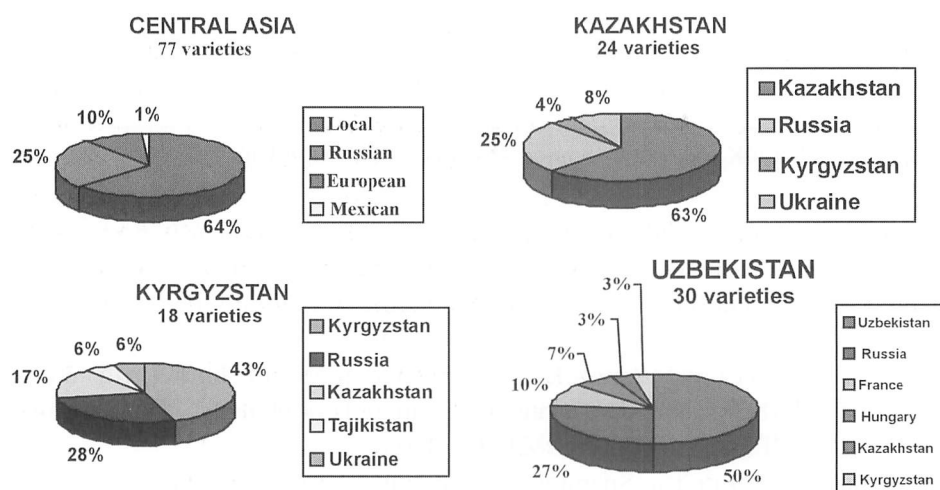


Fig. 4. The distribution of the winter wheat varieties in Central Asia and selected countries in 2001 by origin (Source: GTZ-CIMMYT, 2003).

Since 1994-95, wheat research in the region was substantially influenced by the development of international linkages, especially in breeding. The international centers, CIMMYT and ICARDA, established the germplasm exchange primarily through the winter wheat program Turkey-CIMMYT-ICARDA located in Turkey. Regular international nurseries from international programs in Turkey,

Syria, and Mexico were sent to the region for selection and utilization either directly as varieties or for crosses. At the same time, the wheat varieties from the region were sent to Turkey and were globally tested through different nurseries. It appeared that the germplasm from international programs was very well adapted to the conditions of the region and assured healthy competition with the Russian and locally developed varieties.

By 2003, several wheat varieties were officially tested in the region for possible release (Table 4). The advantage of these new varieties is high yield, and excellent resistance to leaf diseases especially yellow rust. The grain quality of this germplasm has to be verified during the tests. The sample yield data from Tajikistan is shown in Table 5 illustrating the diversity of the germplasm tested in the country and the relative performance of the introduced and local varieties. A number of other international programs related to development of new varieties and their promotion are under way supported by German Technical Cooperation Agency (GTZ), USDA through Washington State University and other donors.

CONCLUSIONS

The history of wheat breeding in Central Asia demonstrates that during the last 100 years it transformed from a major crop in the region, being grown both under irrigated and rainfed conditions, to a crop almost entirely grown in the hills and mountains where irrigation is not possible. While cotton dominated, wheat research and breeding remained almost forgotten and in some countries was not continuous. As a result when the region needed the grain and turned to self-sufficiency in the early and mid-1990s, suitable varieties for irrigated conditions were not available. The land was grown to introduced germplasm which provided sufficient yield.

The next step of producing the same or higher yield more efficiently with less water and pesticides required well adapted local varieties which have been developed by early 2000s, frequently in cooperation with international centers. It is difficult to predict how the cotton-wheat competition will evolve the next 10 years. The higher profitability of cotton per unit area remains a very strong factor to decrease the land under wheat. On the other hand, the small private farmers see wheat as a guarantee for their essential food supply. The countries almost reached the self-sufficiency and the governments so far continue encouraging grain production.

The solution for the future is development of wheat varieties and technologies that would provide higher yield using less land and water - a challenge not only for the local scientists but for the global scientific community interested in the sustainable development of this region.

Table 4. Winter wheat varieties originated from international nurseries being officially tested in Central Asian countries.

<u>Country</u>	<u>Year</u>	<u>Variety</u>	<u>Pedigree</u>	<u>Cross ID</u>	<u>Origin</u>	<u>Submitted by:</u>
Kazakhstan	2001	Egemen	BHR/AGA//SNI/3 /TRK13JUP/4/CLLF/3/ II14.53/ODIN//CI13431/WA0	XWN84305	ORMXTCI	Kazakh ARI
Kyrgyzstan	2002	Akdan	0477	SWM5069	MX	Red Fall St.
	2001	Djamin	NS55-58/VEE	SWM833795	MXORTCI	Kyrgyz ARI
	2002		F.474S10.1		ROM	Kyrgyz ARI
	2002	Keremet	Hatusha/KAUZ	CIT89100T	TCI	MIS Farm
					//TRK13	
	2002	Zagadka	CHAM6//F134.71/NAC	CIT922354	TCI	MIS Farm
	2002	Zubkov	1D13/MLT//KAUZ	SWM89Y029H	MXORTCI	MIS Farm
	2002	Azibrosh	OK82282//BOW/NKT YMH/JAR//KKZ/4/63.122. 66.2/NO66/	CMSW90M128	MX-CIT	MIS Farm
	2002	Aychurek	/LOV2/3/KVZ/HYS/5/ EYS/BEZ	YE4615	YE-CIT	MIS Farm
	2002	Cholpon	PYN/BAU	SWM15182	MX	MIS Fram
Tajikistan	2000	Tacicar	TAST/SPRW//ZAR	ICWH840048	TCI	Tajik ARI
	2000	Norman	OR F1.158/FDL//BLO/3 /SHI4414/CROW	ICWH860291	TCI	Tajik ARI
	1999	Kauz	JUP/BJY//URES	CM67458	MX	Tajik ARI
	2002	Alex	PYN/BAU	SWM15182	MXORTCI	Tajik ARI
	2002	Ormon	NWT/3/TAST/SPRW //TAW12399.75	ICWH900335	TCI	Tajik ARI
Turkmenistan	2000	Garagum	TRAKIA/KNR	TE3093	TE	Turkmen ARI
	2000	Guncha	HYS/7C//KRC (ES84-16)/3/SERI	SWM17323	MXTCI	Turkmen ARI
	2000	Bitarap	SN64//SKE/2*ANE/ 3/SX/4/BEZ/5/SERI	SWM866442	MXTCI	Turkmen ARI
Uzbekistan	2000	Dostlik	YMH/TOB//MCD/3/ LIRA	SWM12289	MX	Gallyaoral ARI

Table 5. The yield performance of winter wheat varieties of different origin at three locations in Tajikistan in 2001.

Variety	Origin	Sovetsk.	Kurgan	Nau	Average	Rank
Steklovidnaya 24	Kazakhstan	3.63	3.45	3.00	3.36	1
PYN/BAU	Mexico-Tajikistan	3.66	3.25	3.02	3.31	2
Karlygash	Kazakhstan	3.54	3.55	2.60	3.23	3
Kauz	Mexico	3.64	3.07	2.92	3.21	4
Krasnovodopadskaya 25	Kazakhstan	3.49	3.30	2.70	3.16	5
Jagger	USA	3.40	3.20	2.85	3.15	6
Yanbash	Uzbekistan	3.51	3.10	2.77	3.13	7
Bezostaya 1 (LC)	Russia	3.38	3.05	2.80	3.08	8
Boqamaya 56	Kazakhstan	3.34	3.37	2.25	2.99	9
Zhetisu	Kazakhstan	2.96	3.10	2.87	2.98	10
ZANDER-12	Mexico-Tajikistan	2.98	2.92	3.00	2.97	11
Krasnovodopadskaya 210	Kazakhstan	3.18	3.37	2.32	2.96	12
Ulugbek 600	Uzbekistan	3.06	3.50	2.30	2.95	13
7C (LC)	Mexico	2.24	3.50	3.10	2.95	14

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Promoting Sustainable Maize-Based Cropping Systems in Central Asia and the Caucasus through CIMMYT-NARS Partnership

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ABSTRACT

Maize is an important crop in the countries of Central Asia and the Caucasus and used mainly as animal feed in the form of grain, forage or silage. It is estimated that approximately an area of 700,000 ha are under maize in the region. Kazakhstan, followed by Georgia, are the two largest maize growing countries in the region. Approximately 872,000 tons of grain and 1.3 million tons of silage maize are produced in the Region. The area under maize declined dramatically in the 90s and, since the farmers could not afford to apply the inputs, productivity also declined. With production of maize in the region declining and the countries unable to afford to import feed from elsewhere, the livestock sector has suffered a serious setback.

During the steering committee meeting of the CGIAR-CAC held in 1999, several national agricultural research systems (NARS) expressed a keen desire that CIMMYT should play an active role in promoting sustainable maize production systems in CAC countries. CIMMYT and CAC-NARS together with the support of the CGIAR-Program Facilitation Unit organized the first ever International Maize workshop in the region in September 2000 co-sponsored by CIMMYT, National Academic Center of Agricultural Research (NACAR), Kazakhstan and Kyrgyz Agrarian Academy (KAA). The workshop focused on priority areas for cooperation between CIMMYT and the NARS in the region and development of an Action Plan.

Following the recommendations of the workshop, three international trials :1) CHTSW (subtropical white hybrid trial), 2) CHTSY (subtropical yellow hybrid trial) and 3) EVT 16A - Subtropical yellow varietal trial were evaluated in 2001 cropping season in the eight CAC countries. The top two entries, CMTQ983021 and CMSQ995069, were both QPM hybrids and yielding 26% and 17% better than the local checks in Azerbaijan. CMSQ996906, a yellow QPM hybrid showed great potential in Azerbaijan conditions yielding 46% higher than the local check, followed by a three-way hybrid CMT965024. This was also the top yielder in Georgia, outperforming the local check cultivar Ajameti white by 28%.

Twenty open-pollinated yellow varieties were tested in replicated trials in several countries in the Region. Results from Anny Setti, Turkmenistan, identified an inter-population synthetic variety (Tlaltizapan 9733 x Tlaltizapan 9745) as the best yielder, yielding on par with the local check hybrid and similar in maturity. A similar inter-synthetic variety (Pop. 33 C4 x Pop. 45 C9) yielded 10.4 t ha⁻¹ and 21% higher than the local check, while maintaining similar maturity, in Tserovani, Georgia. Bangalore 9733, an elite OPV from Population 33 yielded as high as 13.7 t/ha under Kazakhstan conditions, yielding on par with the local check hybrid Uzbekistan Dent. The performance of CIMMYT maize germplasm in the Region demonstrates the tremendous potential that it could offer as direct introduction in some environments as well as for introgression into local germplasm in other conditions.

INTRODUCTION

The change from a centralized Communist economy to decentralized market economy has been a turbulent voyage for many of the Republics of the former Soviet Union, and the agricultural sector has been one of the hardest hit. Agricultural production and productivity dropped dramatically in several countries, resulting in food shortage and hyperinflation.

Maize is an important crop in the CAC countries, e.g., Caucasus (Armenia, Azerbaijan, and Georgia) and Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) and used is mainly as animal feed in the form of grain, forage or silage. It is estimated that approximately an area of 700,000 ha are under maize in the region. Kazakhstan followed by Georgia, are the two largest maize-growing countries in the region (Fig. 1). Approximately 872,000 tons of grain and 1.3 million tons of silage maize are produced in the Region (Table 1). The area under maize declined dramatically in the 90s, and since the farmers could not afford to apply the inputs the productivity also declined (Fig. 2).

With production of maize in the Region declining and the countries unable to afford to import feed from elsewhere, the livestock sector suffered a serious setback. Although investment in research on maize improvement was at an all time low in 2000, the public sector national agricultural research systems still plays a dominant role in maize research and extension in the region.

During the steering committee meeting of the CGIAR-CAC held in 1999, several national agricultural research systems expressed a keen desire that CIMMYT should play an active role in promoting sustainable maize production systems in CAC countries. Hence it was decided to explore the potential for maize and the role that CIMMYT can play in the region. A modest seed money of \$20000 was

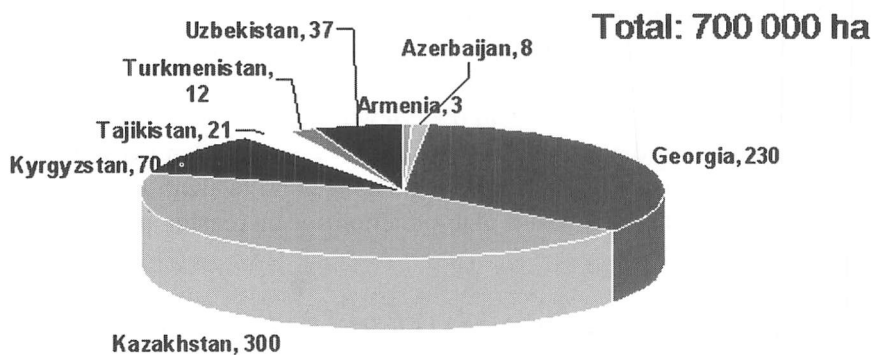


Fig. 1. Maize area in Central Asia and the Caucasus 1999-2000.

Table 1. Maize production 1999-2000.

Country	Grain	Silage	Total
	 10 ³ t		
Armenia	7	10	17
Azerbaijan	25	100	125
Georgia	420	200	620
Kazakhstan	145	420	565
Kyrgyzstan	150	250	400
Tajikistan	30	50	80
Turkmenistan	20	79	90
Uzbekistan	75	200	275
Total	872	1309	2181

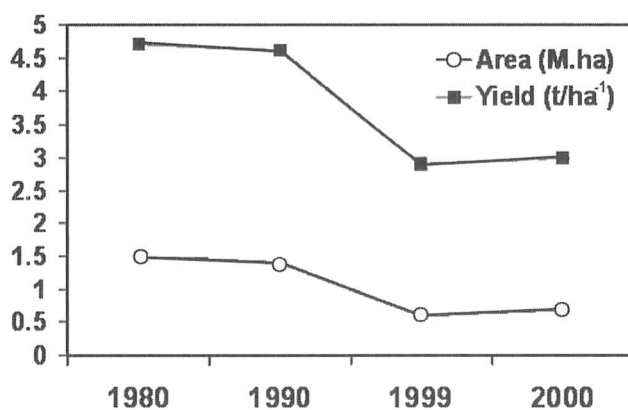


Fig. 2. Trends in maize area and yield 1980-2000.

approved by the Program Steering Committee for this work in 2000. It was decided to organize a workshop and bring together maize researchers from the former Soviet Union with special focus on the CAC countries.

This paper attempts to give: i) an overview of CIMMYT's maize program and the role it can play in the region, ii) potential for collaboration between CIMMYT and CAC-NARS in training, germplasm exchange and evaluation and some preliminary results, and iii) future plan of action for increasing productivity of maize in the region

CIMMYT'S GLOBAL MAIZE RESEARCH PROGRAM

Production Environments in the Developing World

Of some 100 M hectares of maize planted in the developing countries, about 42 M are planted in Asia, 30 M in Latin America, 26 M in Africa, and 2.5 M ha in West Asia/North Africa. In these regions, 50 M ha are grown in the lowland tropics, 18 M in the subtropics, and tropical mid-altitudes environments, 6 M ha in the tropical highlands, and 26 M ha in temperate ecologies. CIMMYT focuses its work mainly on non-temperate maize, as much of the technology for temperate maize is provided by the private sector. Recently CIMMYT refined the maize mega-environment classification using a GIS-based approach (Hartkamp et al., 2000). This provides a better understanding of the target area that CIMMYT is working as based on the climate, soil and other stresses experienced by the maize crop.

Developing-world farmers cultivate a wide array of maize types. They range in maturity from extra-early to extra-late (full season) maize, in grain types from floury, dent, semi-dent, semi-flint, to flint and in grain color from white to yellow to blue. Generally, white maize is consumed as food for human consumption, mostly in Africa and Latin America, and yellow maize used as feed, maize mostly in Asia. However, depending on consumption patterns and culture, one can see the use of yellow maize for food and vice-versa in many countries. Specialty corns such as baby corn, sweet corn, popcorn, waxy corn, high oil corn, etc., are becoming more and more popular in recent years in many countries.

Table 2. World maize production statistics, 1993-1995.

World	Area	Yield	Production
Developing regions	-M ha-	-t ha ⁻¹ -	-M t-
-Africa	26.0	1.56	40.6
-Asia	39.4	3.55	139.9
-Latin America	28.2	2.49	70.1
Industrialized countries	41.4	6.51	269.4
World	135.1	3.85	519.9

Source: FAO Agrostat database

Maize Utilization Trends in the World

More than 500 Mt. t of maize are produced globally, out of which over 60% are produced in the industrialized nations, which have only one-third of the world's maize area. The gap between industrialized and developing countries is narrowing in recent years, but still there is a large untapped potential for maize production in developing countries. This needs to be exploited if we have to keep pace with the current projections of population and income growth and the increasing demand for maize.

Currently, the International Food Policy Research Institute (IFPRI) projects that in the period from 2000-2020, demand for maize in developing countries will grow at an average rate of 2.2% annually. With the land-base for arable agriculture constant, and in some cases shrinking in the developing world, the only solution is increasing production through improved technologies. Fortunately, since yields of maize in the developing world are still low compared to the industrialized world, there are opportunities for meeting this demand by increasing productivity in a sustainable manner.

Maize is a staple food crop in many economies. Throughout large areas of Sub-Saharan Africa, maize is consumed directly as human food. Annual per capita maize consumption levels can be extremely high, especially in Malawi (137 kg), Zambia (113 kg), South Africa (94 kg), and Kenya (93 kg). Similar trends exist in many countries of Central and South America, where maize is consumed as the principal calorie provider in daily diets. For example, in Mexico, the average per capita maize consumption is 127 kg, followed by Guatemala with 103 kg. In Asia, where rice and wheat are the principal food crop, maize is mostly used for animal feed and in some cases for industrial use.

Maize Program's Mission

CIMMYT Maize Program's mission is to serve the needs of the resource-poor maize farmers and consumers in the developing countries and help alleviate poverty by increasing the profitability, productivity and sustainability of maize based farming systems. We do so by working in partnership with colleagues in national agricultural research programs, universities, and other centers of excellence around the world. The Program's broad activities include the following:

- Development and worldwide distribution of higher yielding maize cultivars with built-in genetic resistance to important biotic and abiotic stresses.
- Conservation and distribution of maize genetic resources.
- Strengthening research on natural resource management in maize-based cropping systems.
- Development of new and effective research methodologies.
- Training.
- Consulting.

Structure and Organization Research

The CIMMYT Maize program is organized into four major subprograms based on ecologies - viz. lowland *tropical*, *subtropical*, *mid-altitude* and *highland*. These sub-programs develop improved maize cultivars to serve the needs of the respective ecologies. Several additional disciplinary sub-programs such as *entomology*, *pathology*, *physiology*, *germplasm bank* and *agronomy* not only conduct discipline-oriented research but also work together with the breeders to develop robust maize cultivars with tolerance to various biotic and abiotic stresses.

Recently, we started a dedicated pre-breeding unit to utilize the germplasm bank accession more effectively and to develop new sources of breeding materials for use by the breeders. A separate Training Unit handles all the training needs of the program. The breeding training are handled globally in Mexico whereas the agronomy, and crop-management training has been devolved to the regional programs and subsequently to the national programs.

CIMMYT maize program deploys more than two-thirds of its resources and staff in the various regional programs in Asia, Africa and Latin America. While the global germplasm development needs are served from headquarters in Mexico, region-specific problems are handled by our scientists in the regions. For example, CIMMYT researchers in Cali, Colombia, work on developing germplasm with acid-soil tolerance, whereas our scientists in Asia work on downy mildew resistance, and our researchers in Sub-Saharan Africa concentrate on developing resistance to maize streak virus.

CIMMYT strives to develop a product that is needed by the developing world farmers. Since both open-pollinated varieties and hybrids are required in different parts of the developing world, our research seeks to maintain a balance in the development of these two products. In fact in recent years, our breeders have refined the breeding methodologies in such a way so as to produce open-pollinated cultivars (synthetics) as well as inbreds and hybrids at the same time.

Maize Germplasm Development and Improvement

Extensive research over the last three decades has resulted in a wealth of maize germplasm available to the national programs from CIMMYT. Over 40 gene pools and 50 populations representing various ecologies, and grain color and, grain type were developed and improved in partnership with NARS. A complete listing of the germplasm available can be found in one of our recent International Maize Testing Reports (CIMMYT, 2000) or through our web page.

Maize populations go through systematic recurrent selection scheme involving international progeny testing trials conducted in partnership with national system. Depending on the selection scheme used, one cycle of improvement takes between 2 to 3 years to complete. Until the mid-80s, CIMMYT relied heavily on intra-population improvement. In recent years, most of the maize populations are classified according to their heterotic pattern and improved using reciprocal recurrent selection involving S1-S3 x tester progenies. Significant genetic gains for yield and other traits have been achieved through the recurrent selection schemes in CIMMYT populations (Pandey et al., 1986, 1987).

In the mid-80s CIMMYT initiated hybrid maize program in response to increased demand for hybrid-oriented products from the national programs. In 1994, the first International Maize Hybrid Trials were distributed by CIMMYT. The response to these trials and the hybrid products from NARS has been extremely positive. CIMMYT has so far released 497 inbred lines as CIMMYT maize lines (CMLs) and made them freely available to National Programs.

Incorporating Stress Tolerance into Germplasm

Breeding for stress -tolerance has been a vital strategy of CIMMYT since its inception in the 1960s. Extensive research has been done on breeding for tolerance to biotic stresses, such as insects and diseases, and for abiotic stresses in maize, such as drought, low-N, acid soil, etc. The success in breeding for drought, low-N and insect tolerance is widely documented. Now the screening and selection for stress-tolerance in maize germplasm is an integral part of every breeding program at CIMMYT and we aim to develop robust germplasm that not only yield better but also possess stress tolerance. Both conventional plant breeding

and modern tools such as molecular markers are used in our breeding approaches to building stress tolerance.

Nutritional Security

Significant progress has been in breeding for improving the quality of maize. We started in the late 1960s on work with opaque-2 maize to improve the quality of the protein. The mutant opaque-2 doubles the content of two essential amino acids in maize lysine and tryptophan, which are critical for human nutrition, especially for growing children. However, the opaque-2 gene also conferred some undesirable traits such as soft endosperm, susceptibility to ear rots and stored product pests, and low yield.

Through three decades of painstaking systematic breeding efforts, scientists rectified these drawbacks and developed what is now called as the Quality Protein Maize (QPM), which not only has the enhanced quality of protein by doubling the quantity of lysine and tryptophan but yields on a par or higher than normal hybrids, and also has a higher level of resistance to ear rot and other pests. In recent years, the impact of QPM has grown considerably in the developing world. From less than four countries that grew QPM in 1997, over 22 countries currently grow QPM based on CIMMYT germplasm. CIMMYT is also actively looking for ways to improve the micro nutrient content of maize grain by enhancing the level of iron, zinc, molybdenum, vitamin A, etc. CIMMYT's researchers were awarded the "World Food Prize" in 2000 for developing and disseminating QPM in the developing world.

International Maize Testing Network

CIMMYT maize program coordinates an extensive international maize testing network. Currently over 1500 collaborators from around the world participate in it by evaluating germplasm, providing valuable feedback in the form of trial results and their observations, and soliciting and utilizing CIMMYT germplasm. Every year, thousands of evaluation trials, that included OPVs and hybrids, are tested in the developing countries. These trials serve as an effective mechanism for dissemination of adapted germplasm as well as provide useful data to breeders to assist in improving these populations. Results from these trials are published as annual reports. Recently, we have included these results in our web page for easy access (www.cimmyt.org/imtu). Cooperators can access the results, request trials and germplasm through this website. The maize program has a policy of providing free access to its germplasm to National program for use in their research. national programs scientists can request maize germplasm from CIMMYT by writing to the Director, Maize Program, CIMMYT, Apdo. Postal 6-641, Mexico D.F., Mexico 06600.

Training

In the last 30 years, over 4000 maize researchers from approximately 80 countries around the world have been trained at CIMMYT. The Center offers a 4-month, basic maize-breeding course for young and entry-level researchers and a 6-week, advanced maize breeding course for experienced senior researchers. In addition, training on seed production, hybrid breeding, agronomy, crop management, and use of computers in agriculture is given globally as well as in the regions. Training is considered an important component of its human resource development activity, and invites visiting scientists to work on specific projects for durations ranging from less than a month to one year.

Impact of Maize Research

CIMMYT's investment in maize research in the past three decades has paid rich dividends. Over 1000 maize cultivars released in the developing world trace their origin back to the Center's germplasm, and some recent estimates puts the area under CIMMYT-derived maize germplasm in the developing world at over 30 M hectares. More than 50% of the area planted to modern maize varieties in the developing world contains CIMMYT germplasm. A recent study conducted by the Economics Program estimates that in Latin America over 89% of the non-temperate maize seed sold by the private sector are based on CIMMYT germplasm.

Collaborative Maize Research with Central Asia

With the changes happening in the former Soviet Union countries, the transition from a centralized economy to market economy has not been easy. The maize area, production and productivity has suffered heavily and declined in the region in the nineties. Nevertheless, maize continues to be an important crop for many countries in the region. As a feed crop, maize is second to none, and there is an urgent need to increase its production and productivity of maize. CIMMYT can play a very vital role in providing the much-needed technology and training to accelerate this process;. It's subtropical and mid-altitude maize germplasm can be used in many countries, either directly or through introgression.

We will work with the national programs to develop and promote a sustainable seed production infrastructure in the region. Through its training and visiting-scientist program, the Centers can assist with providing training to the research personnel working on maize in these countries. We strongly believe that there is a bright future for maize in the region, and CIMMYT and Central Asia together and the Caucasus can chart a very exciting future, with the hope that the donor community will decide to invest in this vital activity.

CIMMYT and region's national programs, together with the support of the CGIAR-Program Facilitation Unit organized the first ever International Maize workshop in the region in September 2000. We will present the salient findings, recommendations, and follow-up to this workshop at Almaty, Kazakhstan, and Bishkek, Kyrgyzstan.

This workshop was co-sponsored by CIMMYT, the National Academic Center of Agricultural Research, Kazakhstan, and the Kyrgyz Agrarian Academy. The Workshop was attended by over 30 participants representing 10 countries. Apart from the eight CAC countries, representatives from Russia and Yugoslavia also participated. Many of the participants were leaders of the maize program in their respective national programs.



Fig. 3. Participants at the International Workshop on Maize Production and Improvement in CAC held at Almaty, Kazakhstan and Bishkek, Kyrgyzstan, September 4-9, 2000.

The Workshop was followed by two days of presentations on the status of maize production and research in their countries by participants from Armenia, Azerbaijan, Georgia, South Kazakhstan, North Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Russia, Yugoslavia. The workshop also focused on priority areas for cooperation between CIMMYT and the national systems in the region and development of action plan. A questionnaire was designed and distributed to all the participants to gather information on the status of maize in each country. The information gathered was useful in providing a benchmark to work with. The following areas were identified as top priority.

Germplasm Introduction and Evaluation

It was agreed that CIMMYT would send a set of its potential elite germplasm (OPVs, hybrids, elites) mostly subtropical/temperate types for evaluation in the region to identify the potential for its materials. Similarly, we will receive the local materials from the Region for evaluation and introgression at CIMMYT. One of the most promising materials identified was an yellow hybrid called "Manas" released in Kyrgyzstan. Considerable interest was shown for testing CIMMYT-derived drought tolerant, low-N tolerant, QPM, and insect-resistant germplasm.

Training

There is an immediate and urgent need for the Center to train maize scientists from the Region through its training and visiting scientist program in Mexico. Those selected will undergo intensive English training in Almaty or Tashkent before going to Mexico. Regional training was also considered as an option in addition to headquarters' training.

Information Technology

CIMMYT will add the CAC-NARS in its mailing list for distributing publications on maize. Copies of the CIMMYT maize line booklet, field guides for maize diseases, insects, and physiology were distributed. Keen interest in getting the national programs upgraded in their computing needs, and a possible training course in the future on the use of the Fieldbook was discussed. The proceedings of the workshop was published in Russian and English and distributed during the following Program Scientific Committee meeting in June 2001, at Almaty, Kazakhstan.

Training

Based on the recommendation of the Workshop in September, 2000, a candidate was identified from the region to attend the 4-month maize breeding training course to be held at El-Batan, Mexico from June 16, 2001. The candidate, Mr. Nasredin Sharipov from Kazakhstan completed an intensive English course before coming to Mexico. Mr. Sharipov has successfully completed the maize training course and is back in Kazakhstan working for the national program.

Germplasm Distribution

Improved maize germplasm comprising of 21 open-pollinated varieties and populations and nine hybrids in both normal and quality protein maize germplasm, and nine inbreds were sent from CIMMYT, Mexico to CIMMYT

office in Kazakhstan for distribution to the CAC countries in the region. Three international trials: 1), CHTSW (subtropical white hybrid trial), 2) CHTSY (subtropical yellow hybrid trial), and 3) EVT 16A - Subtropical yellow varietal trial were distributed for evaluation in the 2001 cropping season in the eight CAC countries. Overall 207 kg of seeds were shipped to the region. The performance of CIMMYT Hybrid Trial, subtropical white (CHTSW) comprising of 30 entries planted in three replications at two locations from Azerbaijan and Turkmenistan during 2001 are presented in Table 3 and 4.

Table 3. Performance of subtropical white hybrids in Zakata City, Azerbaijan (CHTSW 2001).

Ent. No.	Pedigree	Grain yield (Kg/ha)	%Over best check	Days Silk (d)	Days Pollen (d)	Plant ht (cm)	Ear ht (cm)	Plant Harv (no.)	Root Lodg (%)	Husk Cover (1-5)	Ustilago maydis (1-5)	Helm turicum (1-5)
25	CMTQ983021	6172	126	114	105	292	113	19	0.0	1.0	1.0	3.7
28	CMSQ995069	5739	117	113	103	238	100	20	0.0	1.0	1.0	3.0
8	CMS996483	5138	105	104	94	251	111	20	0.0	1.0	1.3	4.0
5	CMT996409	5100	104	111	102	283	119	20	0.0	1.0	1.0	4.3
26	CMTQ995071	5078	104	112	105	313	145	20	0.0	1.0	1.7	3.3
2	CMS996025	5034	103	104	99	289	136	20	0.0	1.3	1.7	3.0
14	CMT005009	4896	100	117	109	278	114	20	0.0	1.0	1.0	1.7
19	CMT005019	4702	96	112	99	257	106	18	0.0	1.0	1.7	5.0
1	CMS996073	4234	86	98	93	215	97	18	0.0	1.3	1.3	3.0
23	CMS935005	3877	79	98	93	214	90	18	0.0	1.7	1.0	3.0
7	CMT996397	3782	77	116	111	302	131	19	0.0	1.0	2.0	1.0
11	CMT005003	3772	77	94	87	254	107	19	0.0	1.3	1.7	3.3
13	CMT005007	3656	75	93	88	199	87	19	0.0	1.0	1.0	4.3
3	CMS996135	3611	74	112	101	281	111	19	0.0	1.0	1.0	4.0
12	CMT005005	3246	66	113	106	249	102	20	3.3	1.0	1.7	4.3
6	CMT996415	3218	66	115	102	310	131	18	0.0	1.0	1.7	2.3
22	CMS975089	3096	63	94	89	213	93	19	0.0	1.7	1.3	3.3
9	CMS996487	3053	62	93	83	223	83	19	0.0	1.3	2.3	2.7
27	CMSQ995907	2854	58	105	99	244	95	19	0.0	1.0	1.0	1.7
4	CMT996393	2848	58	114	108	256	109	19	0.0	1.0	1.0	2.0
24	CMSQ995069	2676	55	91	85	251	109	20	11.7	1.7	1.7	2.7
21	CMT935036	2591	53	125	111	273	106	20	0.0	1.0	1.0	4.3
10	CMT005001	2580	53	96	89	217	94	18	0.0	1.3	2.7	2.3
20	CMT005021	2307	47	105	98	282	133	19	0.0	1.3	1.7	3.7
16	CMS005013	2236	46	120	110	292	127	20	0.0	1.0	1.0	4.0
17	CMT005015	1979	40	104	93	229	103	17	0.0	1.3	2.3	3.3
15	CMS005011	1719	35	122	111	306	126	19	3.3	1.0	1.7	1.3
18	CMT005017	1480	30	110	103	257	108	19	0.0	1.0	2.3	4.0
	Means	3596	-	107	99	260	110	19	0.7	1.2	1.5	3.2
	Maximum	6172	-	125	111	313	145	20	11.7	1.7	2.7	5.0
	Minimum	1480	-	91	83	199	83	17	0.0	1.0	1.0	1.0
	CHECKS (Testigos):											
29	Local Check-1	4903	-	78	74	229	104	17	3.9	2.0	1.0	1.3
30	Local Check-2	3641	-	77	75	243	102	15	0.0	2.0	1.3	1.0
	CHECK MEANS	4272	-	78	75	236	103	16	2.0	2.0	1.2	1.2
	5% LSD	22.1	-	4.9	4.5	37.7	18.0	1.7				
	C.V.%		-	2.3	2.3	7.3	8.1	4.6				

Several white hybrids performed better than the local check materials in both locations. The top two entries, CMTQ983021 and CMSQ995069, were both QPM hybrids and yielded 26% and 17% better than the local checks in Azerbaijan. However, they were also later in maturity. In Turkmenistan, hybrids CMS975089 and CMT996409 yielded on a par with local checks and showed similar maturity.

Table 4. Performance of subtropical white hybrids in Anny Settl, Turkmenistan (CHTSW 2001).

Ent. No.	Pedigree	Grain Yield (K/ha)	%Over best check	Days Silk (d)	Days Pollen (d)	Plant ht. (cm)	Ear ht. (cm)	Plant Harv. (no.)	Moisture Plant (%)	Ear/ (ratio)
22	CMS975089	3788	100	74	72	257	109	21	7.0	1.2
5	CMT996409	3733	99	81	79	284	128	20	8.4	1.1
9	CMS996487	3689	98	73	71	287	90	21	9.6	1.2
10	CMT005001	3687	98	79	75	283	112	18	9.5	1.1
11	CMT005003	3659	97	75	72	290	113	15	10.2	1.5
13	CMT005007	2527	67	78	75	252	93	19	7.1	1.4
8	CMS996483	2523	67	82	78	267	121	18	7.3	1.7
24	CMSQ995069	2465	65	77	75	281	115	17	9.5	1.2
27	CMSQ995907	1902	50	79	77	275	129	19	6.7	1.6
25	CMTQ983021	1885	50	84	77	272	137	17	7.6	1.4
26	CMTQ995071	1880	50	80	76	302	138	18	7.7	1.7
1	CMS996073	1876	50	79	77	264	102	16	7.9	1.5
23	CMS935005	1876	50	73	73	269	98	18	8.0	1.2
17	CMT005015	1871	50	84	80	262	113	22	8.0	0.6
3	CMS996135	1870	50	81	79	308	126	17	8.2	1.4
2	CMS996025	1860	49	81	78	304	154	19	8.7	1.0
19	CMT005019	1857	49	82	79	278	130	23	8.8	0.9
6	CMT996415	1834	49	81	77	284	132	19	9.9	0.8
4	CMT996393	1833	49	81	78	273	101	22	10.0	0.9
14	CMT005009	1271	34	82	79	285	139	15	6.5	1.6
28	CMSQ995069	1261	33	81	75	277	134	17	7.8	1.1
21	CMT935036	1249	33	78	75	254	121	18	7.9	0.7
18	CMT005017	1245	33	82	79	300	142	17	8.2	0.9
12	CMT005005	1241	33	80	76	274	126	20	8.8	1.4
20	CMT005021	636	17	82	79	271	136	18	6.4	1.2
7	CMT996397	.	.	80	75	290	162	18	8.9	0.7
15	CMS005011	.	.	82	78	269	138	19	9.6	0.3
16	CMS005013	.	.	81	77	282	153	18	6.8	0.6
	Means	2141	-	80	76	278	125	18	8.2	1.1
	Maximum	3788	-	84	80	308	162	23	10.2	1.7
	Minimum	636	-	73	71	252	90	15	6.4	0.3
CHECKS (Testigos):										
30	Local Check-2	3774	-	73	73	259	99	10	7.4	1.7
29	Local Check-1	3667	-	80	76	290	129	17	10.0	1.1
	CHECK MEANS		-	76	74	274	114	13	8.7	1.4
	5% LSD	98.7	-	5.8	4.8	25.2	19.0	5.0	2.4	
	C.V.%	24.1	-	3.6	3.1	4.5	7.6	13.8	14.3	

Performance of CIMMYT Hybrid Trial, subtropical yellow (CHTSY) comprising 20 entries, including several QPM hybrids, was planted in three replications in two locations from Azerbaijan and Georgia during 2001 are presented in Fig. 4 and Table 5, respectively. CMSQ996906, a yellow QPM hybrid showed great potential in Azerbaijan conditions yielding 46% higher than the local check followed by a three-way hybrid CMT965024 (Fig 4.). However, these hybrids, as in the case of yellows, took longer time to maturity. This suggests that while yield potential is high in CIMMYT materials, there is a need for making them early maturity if they have to be adapted to local conditions. CMT965024 also was the top yielder in Georgia, outperforming the local check cultivar Ajameti white by 28%. The consistency of this hybrid in both countries shows the broad adaptation of CIMMYT germplasm in the region.

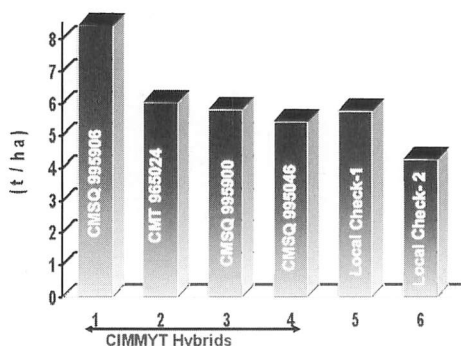


Fig. 4. Mean grain yield of elite subtropical yellow hybrids in Zakatala, Azerbaijan (CHTSY-2001).

Twenty open-pollinated yellow varieties were tested in replicated trials in several countries in the Region and results from two locations are presented below in Table 6 and Fig. 5. Results from Anny Setti, Turkmenistan identified an inter-population synthetic variety (Tlaltizapan 9733 x Tlaltizapan 9745) as the best yielder, yielding on par with the local check hybrid and similar in maturity.

A similar inter-synthetic variety (Pop. 33 C4 x Pop. 45 C9) yielded 10.4 t/ha and 21% higher than the local check while maintaining similar maturity in Tserovani, Georgia. Bangalore 9733, an elite OPV from Population 33 yielded as high as 13.7 t/ha under Kazakhstan conditions, yielding on par with the local check hybrid Uzbekistan dent (Fig. 5).

The performance of CIMMYT maize germplasm in its first year of extensive testing in the region demonstrate the tremendous potential that it could offer as direct introduction in some environments as well as for introgression into local germplasm in other conditions. Quality protein maize hybrids show excellent potential for increasing maize yields as well as in providing nutritional security to the resource poor farmers in the region.

Table 5. Performance of subtropical yellow hybrids in Tserovani, Georgia (CHTSY 2001).

Ent. No.	Pedigree	Grain yield (Kg/ha)	%Over best check	Days silk (d)	Days pollen (d)	Plant height (cm)	Ear height (cm)	Plant harv (no.)	Stem lodg (%)	Root lodg (%)	Ear rot (%)	Ear asp. (1-5)	Plants asp. (1-5)	Hust cove (1-5)
8	CMT965024	9910	128	93	94	247	132	36	0.0	0.0	3.0	3.0	3.0	2.0
2	CMS975004	7881	102	96	97	251	140	35	0.0	0.0	3.0	3.0	3.0	2.0
10	CMT995894	7761	100	83	86	203	120	32	0.0	0.0	3.0	3.0	3.0	3.0
3	CMS975076	7164	92	96	98	252	148	33	0.0	0.0	3.0	3.0	3.0	1.0
1	CMS005000	5731	74	91	94	196	106	32	0.0	0.0	4.0	2.0	1.0	2.0
6	CMT995888	5612	72	84	85	226	134	31	0.0	0.0	6.0	2.0	.	2.0
11	CMSQ995896	4537	58	96	99	250	180	31	0.0	0.0	6.0	3.0	2.0	2.0
5	CMS975319	4299	55	85	87	172	90	34	0.0	15.0	8.0	2.0	2.0	2.0
9	CMT995892	3940	51	83	86	237	160	31	0.0	0.0	7.0	4.0	2.0	2.0
17	CMT995458	3821	49	85	88	251	170	34	0.0	0.0	8.0	2.0	2.0	2.0
13	CMSQ995900	3701	48	83	86	244	152	32	0.0	0.0	7.0	2.0	2.0	2.0
14	CMTQ995902	3582	46	98	100	256	186	30	0.0	0.0	8.0	3.0	2.0	2.0
7	CMT995890	2985	38	85	87	256	185	29	0.0	0.0	8.0	3.0	2.0	2.0
18	CMSQ995046	2746	35	88	92	248	164	32	0.0	0.0	9.0	3.0	3.0	2.0
4	CMS975006	.	.	101	101	272	194	34	0.0	0.0	0.0	.	2.0	2.0
12	CMSQ995898	.	.	97	101	223	136	35	0.0	0.0	0.0	.	2.0	2.0
15	CMTQ995904	.	.	95	96	229	128	35	0.0	0.0	0.0	.	2.0	2.0
16	CMSQ995906	.	.	100	103	261	182	35	0.0	0.0	0.0	.	2.0	2.0
	Means	5262	-	91	93	237	150	33	0.0	0.8	4.6	2.7	2.2	2.0
	Maximum	9910	-	101	103	272	194	36	0.0	15.0	9.0	4.0	3.0	3.0
	Minimum	2746	-	83	85	172	90	29	0.0	0.0	0.0	2.0	1.0	1.0
	CHECKS (Testigos):													
19	Ajameti white	7761	-	78	80	196	106	34	0.0	0.0	3.0	2.0	3.0	3.0
20	Tserovaniz	6448	-	80	82	186	95	31	19.4	0.0	3.0	2.0	3.0	2.0
	CHECK MEANS	7104	-	79	81	191	101	33	9.7	0.0	3.0	2.0	3.0	2.5

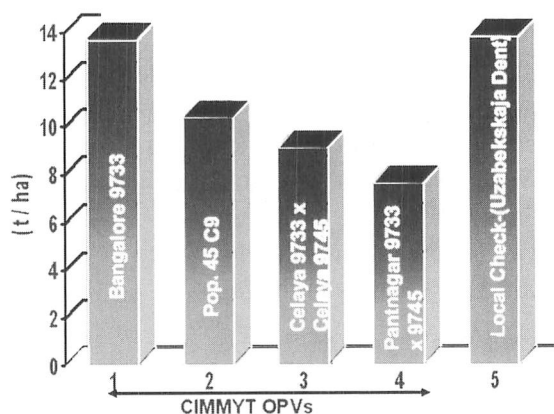


Fig. 5. Mean grain yield of elite subtropical yellow OPVs in Kazakhstan (EVT 16A-2001).

Increasing Maize Productivity: Plan-of-Action

Based on the results obtained so far from the preliminary testing of CIMMYT germplasm, and following on the recommendations of the maize workshop the following action items are planned.

- CIMMYT's subtropical germplasm can be used directly or as an exotic source for introgression in almost all the CAC countries, especially in Georgia, Kazakhstan, Kyrgyzstan, Uzbekistan and Turkmenistan. Further on-farm demonstrations and strip tests should lead to the release of some of these superior cultivars.
- Area under maize in recent years had declined in most of the countries due to poor yields and transition from central economy to market economy. However, maize is considered an important crop in the region and has tremendous potential both for increase in area and productivity. Concerted efforts in partnership with NARS and CIMMYT are required to achieve this in a sustainable manner.
- Private sector practically absent in the region and their role need to be strengthened
- Maize NARS in the region have tremendous need for training and capacity building. This could be done through in-country, and regional training wherever appropriate.
- Emphasis on silage maize due to increasing demand
- Increased testing of Quality Protein Maize (QPM) cultivars in the region for use as animal feed

Acknowledgement

We wish to acknowledge the financial support provided by the CGIAR for organizing the 2001 International Maize Workshop held in Almaty, Kazakhstan, and for the modest financial support to CIMMYT to test the maize germplasm in the region during 2002. We believe that a good start has been made under this project and, with continued financial support from the donor community, CIMMYT and NARS partners could work towards increased productivity and profitability of sustainable maize production systems in the region.

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Present Status and Future Prospects of Food Legumes in Central Asia and the Caucasus

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ABSTRACT

Chickpea, lentil and faba bean are the important cool-season food legumes mainly grown under rainfed conditions in the dry areas. Because of their biological nitrogen-fixing ability these crops play a significant role in the cereal-based farming system that characterizes such areas, especially these with a Mediterranean climate. These legumes are rich in nutritive values (protein, vitamins, and micronutrients) and play an important role in the diet of the poor people in the developing world. In most of the developing countries, for reasons based on food security, monocropping of major cereals has become the practice of the day, and food legumes, which were the part of the sustainable cropping system in the past, are no longer grown extensively. This is the situation of chickpea and lentil in the Central Asian and the Caucasus countries. In this paper, we briefly review the situation of these crops in these countries and suggest ways to increase their production and productivity in larger term.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medik) are the important cool-season food legumes globally (Webb and Hawtin, 1981; Saxena and Singh, 1987). Being leguminous crops, they meet most of their nitrogen (N) requirements from symbiotic N fixation, and thus serve as an important component of subsistence farming in many countries (Beck and Materon, 1988). Chickpea and lentil seeds are nutritionally rich in protein and essential micronutrients, have relatively higher fiber with high digestibility, and are relatively low in anti-nutritional factors. Their straw has a forage value comparable to foliage of

other crops commonly used for livestock feed (Huisman and van der Poel., 1994). Green chickpeas are also used as vegetables.

In most of the developing countries, in the interest of food security, monocropping of major cereals has become the common practice. In the Central Asia and the Caucasus (CAC) region, due to dominance of monoculture during the Soviet Era, chickpea and lentil, which earlier were important cool-season food legumes in sustainable farming systems, turned out to be 'neglected crops', and consequently, their cultivation, research and development virtually stopped. (Malhotra et al., 2000). Consequently, these have become "forgotten crops" for the farmers, consumers, and the scientists in the region. Old Soviet texts note that people used to consume chickpea and lentil as food (mostly as soup), indicating that these crops were cultivated in the region. The need to consume food legumes, in the diets of people in the CAC region, has become more pressing in view of the decrease in animal protein and its high costs (Fig. 1). Scarcity of animal feed also drives the need for higher production of leguminous crops.

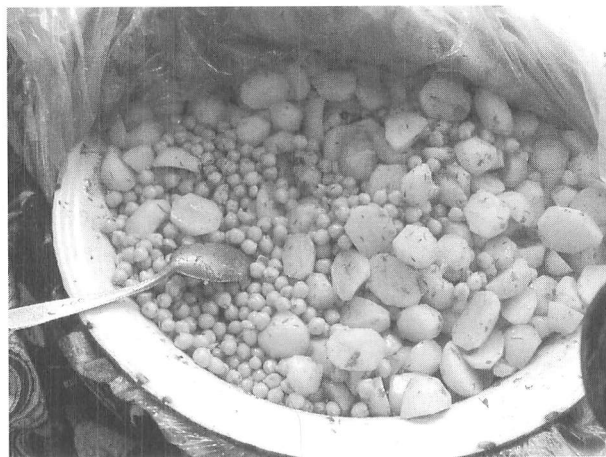


Fig. 1. Chickpea preparation used as a breakfast being sold in the market in Uzbekistan.

Realizing the need for crop diversification, research administrators/policymakers and scientists in the region launched a food-legume research program in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria. Although ICARDA had been collaborating with the erstwhile USSR, and later with these independent States since the beginning, efforts were strengthened further in 1998 when the Consultative Group on International Agricultural Research (CGIAR) established its Program Facilitation Unit (PFU) for CAC countries with its headquarters at Tashkent in Uzbekistan.

The establishment of this Regional Office brought the scientists on a common platform, where the regional research problems could be discussed and resolved jointly (Fig. 2). Looking into the importance of chickpea and lentil in the sustainable crop production systems and nutritional security of the growing population of the region, ICARDA has put forward its thrust on Kabuli chickpea and lentil improvement.



Fig. 2. Scientists from Central Asia and the Caucasus seeing the performance of chickpea lines at Krasney Vodapod (Uzbekistan) during the regional food-legume traveling workshop.

PRODUCTIVITY

Chickpea and lentil have been grown in Central Asia and the Caucasus countries since time immemorial, but individual country statistics are either not available or are unreliable. We collected estimates from different legume researchers from these countries, and these are presented in Table 1. Total arable area in the countries of the region is estimated to be 26,592,500 hectares, of which legumes occupy about 157,48 hectares. Chickpea is most important among the legumes, and occupies about 86,490 ha, with a productivity of 783 kg ha.⁻¹ Of this, Uzbekistan alone grows chickpeas in about 60,510 ha, with a productivity of 720 kg ha.⁻¹ Other countries, however, grow little chickpea, with an area ranging between 2,380 to 6,330 ha, with the exception of Armenia, which grows as little as 140 ha. Chickpea and lentil, in general, are grown as rainfed crops with spring season on conserved moisture, except in some lowland areas in Uzbekistan where the crops are grown in winter.

Table 1. Food legume production in different countries of Central Asia and the Caucasus during 1999.

Country	Rainfed arable area	Legumes			Chickpea			Lentil		
		<u>Area</u>	<u>Production</u>	<u>Productivity</u>	<u>Area</u>	<u>Production</u>	<u>Productivity</u>	<u>Area</u>	<u>Production</u>	<u>Productivity</u>
	(ha x10 ³)	(ha x10 ³)	(tons x 10 ³)	(kg/ha)	(ha x10 ³)	(tons x 10 ³)	(kg ha ⁻¹)	(ha x10 ³)	(tons 10 ³)	(kg ha ⁻¹)
Armenia	483	1.8	1.7	960	0.1	0.2	1310	0.1	0.1	880
Azerbaijan	1,500	12.1	11.9	980	6.3	7.1	1120	1.1	0.6	520
Georgia	799	25.0	30.3	1210	4.4	5.4	1140	2.2	1.5	680
Kazakhstan	15,300	14.2	7.7	540	5.1	3.2	0620	1.2	0.5	380
Kyrgyzstan	1,400	7.5	6.6	880	2.4	2.3	980	0.7	0.4	480
Uzbekistan	4,500	70.6	52.9	750	60.5	43.6	720	2.3	1.3	560
Tajikistan	810	20.1	15.7	780	4.1	2.8	690	5.5	2.6	480
Turkmenistan	1,800	6.2	5.1	820	3.5	3.1	910	1.2	0.7	560
Total	26592	157.5	131.8	6920	86.4	67.7	783*	14.3	7.6	528*

Source: Personal communication from scientists in these countries.

Constraints

In the former Union of Soviet Socialist Republics (USSR), research on genetic resources and breeding was centrally planned and managed, but under independent links between different individual Republics and the Vavilov All-Russian Research Institute of Plant Industry in St. Petersburg. Following independence in 1991, this linkage was broken and the political and structural changes have left the national programs seriously under-resourced and entirely dependent on introduced germplasm and improved breeding lines.

As chickpea and lentil are mainly grown in spring under conserved moisture, drought is a common stress throughout the region. In other areas, cold at the seedling stage and drought and high temperatures at flowering and pod-setting stage are the most important stresses affecting the crops. *Ascochyta* blight disease in chickpea, caused by *Ascochyta rabiei* [Pass.] Labr., is an important biotic stress affecting seed yield in Uzbekistan and Azerbaijan (Amanov et al., 1990). In some areas, weeds also cause serious damage to both the crops. Furthermore, the agronomy of these crops needs to be demonstrated throughout the region. There is presently little domestic demand within the region, which obviously limits the marketing of these crops.

PRESENT STATUS

Food legumes in CAC countries are seen as indispensable protein and energy source and as potential crops for diversification so as to ensure sustainable farming systems, which is currently based on either cotton or wheat monoculture. Several varieties of chickpea were developed by mass selection in Kazakhstan, Uzbekistan, Tadjikistan, Turkmenistan and the Trans-Caucasus. Several perennial species of *Cicer* are native to this region. Also, concerted efforts have been made by the Uzbek Research Institute of Plant Industry (UzRIPI) to evaluate some of the genetic resources lines for various traits, including *Ascochyta* blight, and several sources of resistance have been identified. Currently, UzRIPI has 1280 accessions of food legumes in the gene bank.

In addition, high-yielding lines have been developed through hybridization and selection and recommended for general cultivation in Uzbekistan and other CAC countries. These chickpea lines included: Azerbaijansky 583, AZNII 303, AZNII 304, Milutinsky 4, Milutinsky 6, Uzbekistansky 8, Ulduz, Camilla, Zornukhat, and Uzbekistan 32. Hybridization resulted in such lines as K-368, K-909 from Czechoslovakia, K1226 (Moldavia), K-427 from Syria, and K 1403 (VIR 32) from the former Soviet Union, and a large number of other lines from different countries (Chekalin and Shchelko, 1987).

A project on germplasm conservation, adaptation and enhancement, for diversification and intensification of agricultural production in the region, was initiated in 1998 under the CGIAR and in the framework of the Collaborative Research Program for Sustainable Agricultural Development. Since then, a large number of elite lines of chickpea and lentil have been supplied by ICARDA. Efforts are also being made to strengthen the national agricultural research programs capability and linkage among different CAC countries either through residential training courses or study visits to ICARDA, or through in-country and regional training courses. The major institutions involved in the CAC countries for food legume improvement work include:

- Armenian Research Center for Farming and Crop Protection, Armenia.
- Azerbaijan Research Institute of Agriculture, Azerbaijan.
- Georgian Agrarian Academy of Agricultural Sciences (Mtskheta Breeding Station) and Georgian Agrarian University, Georgia.
- Krasnodovopaskaya Experimental Station, Kazakh Research Institute of Grain Farming, Shortandy, and Kazak Scientific Research Institute of Land Management, Kazakhstan.
- Kyrgyz Agrarian Academy, Kyrgyzstan.
- Tajik Agrarian Academy (Tajik Research Institute of Agriculture), Tajikistan.
- Turkmen Research Institute of Agriculture and Water Resources, Turkmenistan.
- Uzbek Scientific Production Center for Agriculture, Andijan Research Institute of Grain, (Galla-Aral Branch of Andijan Research Institute of Grain, Uzbek Research Institute of Plant Industry, Uzbekistan).

SELECTION OF IMPROVED LINES

With the establishment of Coordination Unit of ICARDA for the Central Asian and Caucasus countries in Tashkent, the scientists from ICARDA's headquarters in Aleppo, Syria, cooperated with their counterparts and provided a large number of improved elite lines of chickpea and lentil for their evaluation under local conditions in CAC countries. A summary of the evaluation of the improved materials and selections made under the joint programs in different countries are given here.

Armenia

In the last few years, a large number of food legume nurseries received from ICARDA have been tested in Armenia, and three promising lines of chickpea, FLIP 97-121C, FLIP 98-130C and FLIP 98-126C for spring planting; and FLIP 97-223C for winter planting were selected. These lines have been included for planting under on-farm trails and field demonstrations in different places. Similarly four elite lentil lines, ILL 5582, ILL 6037, ILL 6199 and ILL 8063, were identified for future release.

Azerbaijan

In Azerbaijan, one chickpea line, FLIP 95-65C ('Narmin'), and one lentil line, ILL 6037 ('Arzoo'), has been proposed for release. The selected line outyielded the chickpea check Behovskaya by 18-20% during the last 3 years. Date of planting experiments further revealed that planting in winter gave much higher yield compared to traditional spring-planted chickpea. A few more ICARDA-supplied chickpea lines, which were planted in winter under similar conditions, showed encouraging results. These lines were totally free of *Ascochyta* blight disease compared to the local 'Yerli Forma', which was completely killed by the disease.

These new lines are tall, thus suitable for mechanical harvesting, and also possess bigger seed size, which are liked by both farmers and consumers. In lentil, the selected promising lines ILL 6037 and ILL 8119 have tall stature, high yield, large seed size, better standing ability, and high biomass, and are suitable for mechanical harvesting. Through continuous supply of elite genetic materials from ICARDA, the food legume improvement program of Azerbaijan Agriculture Research Institute has identified large a number of chickpea (FLIP 95-45C, FLIP 95-55C, FLIP 94-25C and 93-124C) and lentil (ILL 8119) lines for further evaluation. Seed increase of these lines is being done for their dissemination in the country.

Georgia

In Georgia, one chickpea variety, 'ELIXIR' (ILC 533) and one lentil variety, "Pablo" (ILL 759) have been released for general cultivation in Georgia by the Mtskheta Breeding Station (Fig. 3). The chickpea variety 'ELIXIR' gave an average yield of 3.5-4.0 t ha⁻¹, while the lentil variety 'Pablo' produced 2.5-3.0 t ha⁻¹. Because of higher yield, better standing ability, and larger seed size the farmers like these varieties. The farmers in the Marneuli, Gurdjaani and Signaghi regions of Georgia are now cultivating these varieties. In addition, seed multiplication of

these varieties and other elite lines are underway at the station for large-scale farmer's field demonstrations and future seed distribution to the farmers.

The Station has also identified a number of promising lines, ILL 8070 and ILL 7940 in lentil, and ILC 3279 and ILC 6249 in chickpeas, for future releases. In addition, a few more lines, including FLIP 95-51C, FLIP 98-44C in chickpea, and ILL 465, ILL 7115, ILL 1918, ILL8145, ILL 7940 and ILL 8070 in lentil, have been identified for multi-location and on-farm evaluation.

The Georgia Agrarian State University is actively involved in agronomic research, including evaluation of new improved materials of food legumes and also in transfer of technology to the farmers through its strong linkages with the farmers and Extension Wing of the Ministry of Agriculture. Under the supervision of the university, 60 ha of chickpea variety 'Zedazeni' and 7 ha of 'ELIXIR'nin the Sheraki and Misakcieli regions, and 16 ha of 'Shiraqui' and 4.5 ha of 'Pablo' lentil varieties were planted in Narikwal region for demonstration and seed increase.



Fig. 3. ICARDA and Georgian breeders selecting lentil lines in Georgia.

Kazakhstan

Stabilization of grain production system in Kazakhstan would require considerable area under food legumes. It is justified to have about 300,000 ha of food legumes in Kazakhstan. During the last 3 years, the testing of breeding material from ICARDA has resulted in identification of new promising lines for direct seed multiplication and use by farmers. In southern Kazakhstan, research on legume improvement is carried out by Research Institute of Agriculture (Almalybak) near

Almaty. The new promising line of chickpea FLIP 97-137 performed very well during 3 years and has been submitted to official State yield trials under the name ICARDA-1. This line out-yielded not only old checks, but also the recently developed local variety Kamilla by a margin of 28%. In lentil, however, two lines namely, ILL 6037, ILL 6434, were identified as high yielding for the Almaty region and are already pre-release stage.

In north Kazakhstan, the Kazak Research Institute of Grain Farming (Shortandy) is the main partner involved in collaboration on legume improvement work. The lines FLIP 95-46C, FLIP 95-45C, ILC 3279 in chickpea and ILL 6037 in lentil have exhibited advantages in earliness, plant architecture, disease resistance, and yield potential. The standard chickpea variety Ubileiniy, and some varieties from Russia were affected by Ascochyta blight, whereas the selected lines showed good resistance. The trials on inoculation of chickpea seed with Rhizobium culture from ICARDA gave higher yields compared to those without inoculation. It was clear that inoculation with Rhizobium is a pre-requisite for chickpea and lentil cultivation in areas in Kazakhstan where these crops were not grown previously.

Evaluation of chickpea at Krasniy-Vodopad (south Kazakhstan) revealed that the lines FLIP 94-25C, FLIP-97-122C, FLIP-97-52C, and FLIP-97-133C performed better than the standard check. These lines are being evaluated under on-farm verification trials in different locations under rainfed conditions (Table 2). Evaluation of chickpea lines planted in winter and spring in south Kazakhstan revealed that winter planting gave almost double the yield when compared with spring plantings

Table 2. Chickpea yield depending on different seeding time.

Seeding time	1996	1997	1998	Average
----- kg ha ⁻¹ -----				
December	840	690	770	770
January	930	530	700	720
February	770	510	670	650
March	740	520	630	630
April	-	130	510	320

Kyrgyzstan

At the Kyrgyz Research Institute of Forages and Pasture two promising lines of chickpea were selected from ICARDA nurseries: FLIP 98-121C, FLIP 97-266C, which have outyielded the local check by 37-88%. Both of them have resistance to ascochyta blight. These promising lines have been included for seed multiplication and will be submitted to SVTC for future release.

Tajikistan

The Tajik Research Institute of Crop Husbandry has succeeded in identifying two promising lines of chickpea, FLIP 97-149C and ILC 3279, and one promising line of lentil, ILL 6037, from ICARDA nurseries. These lines have been submitted to the State Variety Testing Council for release. The chickpea lines have out-yielded the check Mukhtadir by 18-25%. In addition, lines ILL 6037, FLIP 2002-3L, and FLIP 95-22L of lentil and FLIP 99-2C, FLIP 99-9C, FLIP 97-121C, FLIP 97-149C, FLIP 97-189C and FLIP 95-74C in chickpea have been identified as high-yielding, possessing tall plant type which is suitable for mechanical harvesting.

Turkmenistan

In Turkmenistan, the lentil line ILL 468 has exhibited high yield potential during last few years and across locations. In addition, the chickpea lines, FLIP-98-131C, FLIP-82-150C, FLIP-98-48C, and the lentil lines ILL 4400 and ILL-669 has also been identified as high yielding, with better disease resistance and both heat and drought tolerance. These lines will now be submitted to the State Variety Testing Committee for release.

Uzbekistan

Uzbekistan is the major a leading producer of food legumes in the CAC region. The Galla Aral and Andijan Research Institutes are the major research stations involved in the grain legume research. In addition, the Uzbek Research Institute of Plant Industry looks after the introduction and quarantine activities. Agronomic studies revealed that in moderate environments winter chickpea gives much higher yield than traditional spring sowing, which the farmers in Uzbekistan are practicing presently.

Based on last 4-5 years of testing, legume breeders from Galla Aral have identified chickpea lines FLIP 88-85C, FLIP 93-93C, FLIP 97-99C, FLIP 87-8C and FLIP 95-55C for winter sowing. Among these, FLIP 88-85C and FLIP 93-93 have now been proposed for release. Lentil lines, ILL 7172 and ILL 7513, have

given higher yield and are suitable for mechanical harvesting being tall and erect. Of these, ILL 7513 is proposed for release under the popular name 'Oltindon'.

At the Andijan Research Institute, a number of elite chickpea and lentil lines from various ICARDA-supplied nurseries have been selected. The selected chickpea lines, i.e., FLIP 98-23C, FLIP 95-74C, FLIP 97-25C, FLIP 98-44C and FLIP 97-95 are erect with high podding-intensity, early maturity and with large seed size compared to Uzbek-32, the standard check. Of these lines, FLIP 98-23C has shown superior performance at the farmer's fields and is the candidate for release. In case of lentil, bold-seeded lentil lines, ILL 7943, ILL 7985, ILL 8066, ILL 4400, ILL 7946 and ILL 7940, have been identified as promising. Among these, ILL 7943 has shown superior performance under farmer's field conditions and has been identified for release.

To date, 611 accessions of chickpea, 208 accessions of lentil, and 26 wild accessions of lentil have been collected from CAC countries for evaluation and maintenance in the Gene Bank of concerned countries and at ICARDA (Table 3). The existence of genetic variability in these countries clearly indicates that then legumes were earlier grown in these countries.

Table 3. Chickpea and lentil accessions with wild relatives from Central Asian and the Caucasus countries in the ICARDA genebank.

Country of origin	Chickpea	Wild <i>cicer</i>	Lentil	Wild <i>lens</i> ¹
-----No.-----				
Caucasus				
Armenia	49	1	39	1
Azerbaijan	115	0	61	0
Georgia	11	0	15	0
Central Asia				
Kazakhstan	14	0	2	0
Kyrgyz Republic	9	0	0	0
Tajikistan	112	2	74	8
Turkmenistan	14	0	4	5
Uzbekistan	307	0	13	12
Total	611	3	208	26

¹ *Lens orientalis*

FUTURE PROSPECTS

Preliminary results indicate that with the advancement of planting date from spring to early spring and autumn productivity of chickpea and lentil can be increased substantially. Furthermore, in order to diversify the existing production system, *incorporation of food legumes such as chickpea and lentil will make the cropping systems more sustainable and profitable*. It is hoped that in near future, with the existing partnership between the national research programs and international organizations, considerable areas will be brought under both chickpea and lentil cultivation. This will helping in increasing the soil fertility status and also the nutritional status of the people, beside increasing the farm income of resource-poor farmers in these countries.

From overall achievements, it is felt that good progress has been made in four countries (Uzbekistan, Azerbaijan, Georgia, and Kazakhstan) as for as selection of promising chickpea and lentil lines and their release in concerned. Emphasis must now be given to the dissemination of these varieties through supply of quality seeds, farmer's field demonstrations, organization of field days, etc. Emphasis is needed on establishing an appropriate market structure to guarantee economic viability of legumes. Farmers are also to be trained in the legume production technologies. A strong linkage needs to be established among farmers, extensionists, and the researchers. In addition to new genetic materials, ICARDA also proposes to supply bulk quantity of seeds of the released varieties/pre-release lines in order to accelerate their rapid adoption by national programs. Ongoing research collaboration expected to enhance crop diversification in the CAC region.

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Agro-biodiversity Conservation in Central Asia and the Caucasus - a Focus on ICARDA's Recent Collaborative Work

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Abstract

The Central Asia and the Caucas region encompass two major centers of crop origin and diversification. As such the region is home to a wealth of agro-biodiversity that is both regionally and globally important. However, this diversity is under extreme threat due to genetic erosion being caused by a variety of factors such as the rapidly changing agro-ecosystems brought on by the break up of the Soviet Union. Due to the difficult post-Soviet transition phase national programs in the region were unable to maintain the plant genetic resources work begun by the Vavilov Institute during the Soviet era.

In 1999 IPGRI and ICARDA facilitated the formation of a regional plant genetic resource network together with crop specific thematic working groups to promote PGR conservation and utilization. However this initiative has remained largely ineffective due to a variety of factors including financial constraints, lack of regional expertise and a poor understanding of what constitutes PGR work.

To remedy this situation ICARDA has undertaken a practical approach to the development of plant genetic resources work in the region that has included *direct action, capacity development and raising the awareness* of regional policy makers. These initiatives are beginning to have a significant impact and are detailed in this paper.

INTRODUCTION

The Importance of Plant Genetic Diversity

Plants and their spectacular diversity are a fundamental component of the biosphere, which ultimately sustains all life on earth. Moreover, the utilization of this diversity by humans was responsible for the birth of civilization and still remains vital to the development and maintenance of human society. Plants are

the key to food security and directly or indirectly support the livelihoods of every person on earth (FAO, 1996). Thus, the preservation of plant diversity is an activity that has a direct impact on the well-being of every person on the planet. On this issue, the Director General of FAO Jacques Diouf was quoted as saying the following: *"Today the world is not food secure: 800 million people in the developing countries, 200 million of them children, are chronically undernourished. World food production will have to increase by more than 75 per cent over the next 30 years to ensure food supplies for 8.3 billion people by the year 2025, compared to 5.7 billion today"* (FAO, 1996). In light of this pessimistic prognosis, it is widely recognized that conservation and the utilization of plant genetic diversity will need to be carefully managed to contribute to global solutions.

Of immediate importance are those species that are used in agriculture and collectively called plant *genetic resources*. The effective utility of these resources in agro-ecosystems depends upon their diversity, which can be viewed from three different perspectives: *the combinations of species that make up different ecosystems, the number of different species, and the different combinations of genes within a species*. Having all three forms of diversity in an agro-ecosystem ensures long-term stability and productivity of the system.

Intra-specific genetic diversity, whether used directly by the farmer or used as raw material by a plant breeder to create new cultivars, provides an agro-ecosystem with the ability to adapt to changes in the environment (IPGRI, 2001). In other words, a broad pool of genetic resources acts as a reservoir of genetic adaptability that buffer against potentially disastrous changes in the physical, demographic, or economic environments. This intra-specific diversity, contained within traditional and modern crop varieties and their wild relatives and progenitors, is what needs to be conserved.

Genetic Erosion

However, this agrobio-diversity, so vital to agricultural development and food security, is being increasingly threatened. This problem was recognized as early as the 1930s by H. V. Harlan and in the 1950s by Sir Otto Frankel, both of whom were later active in putting plant genetic resource conservations issues on the global agenda (Pistorius, 1997). The problem was elegantly summed up by Erna Bennett, who worked in close collaboration with Otto Frankel, when she made the observation that *".....'erosion' of our biological resources may gravely affect future generations which will, rightly, blame ours for lack of responsibility and foresight"* (Bennett, 1968). More recently a report on the status of the world's plant genetic resources tabled by FAO at the 1996 Leipzig Conference on Plant Genetic Resources indicated that recent losses of world-wide diversity have been large and that the process of erosion is occurring at a rapid rate (FAO, 1996).

The report states that the most significant contemporary cause of genetic erosion was the introduction and spread of modern commercial agriculture and the use of new crop varieties that supplant the traditional, highly variable, landraces or farmer varieties. For example, a study in Korea demonstrated that for 14 crop types, 74 % of the varieties of being grown in 1985 had been replaced by 1993. Likewise, a similar study reported that of the 10,000 wheat varieties used in China in 1949, only 1000 were still being used by the 1970s. Other significant causes for agro-biodiversity loss stated in the report were population pressure, land clearing, environmental degradation and overgrazing

Global Genetic Resources Conservation Initiatives

To combat escalating genetic erosion the International Board for Plant Genetic Resources (IBPGR) was established in 1974 with a mandate to coordinate an international plant genetic resources program. This finally led to the establishment of a global *ex-situ* genetic resource exchange facility and a system of national and international genebanks created to store plant propagules *ex-situ*. At the time of the plant genetic resources status report (FAO, 1996) there were over 1300 *ex-situ* collections worldwide holding a total of over 6.1 million accessions.

The international genebanks were set up within the Consultative Group for International Agricultural Research, (CGIAR) international research centers. Each of these genebanks were assigned a global mandate for a crop type and for a region. The ICARDA genebank, for example, holds bread wheat, durum wheat, barley, chickpea, lentil, faba bean and a number of different forage legume species as well as the wild relatives of the above crops. In general, the accessions within the genebank tend to be landraces or primitive material with only a small percentage of the total collection consisting of improved varieties.

Until 1998, ICARDA's mandate area included only West Asia and North Africa. This mandate of service was later extended to include the newly independent ex-Soviet Central Asian and the Caucasus countries (CAC) of Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan. Since 1999, the ICARDA Genetic Resource Unit (GRU) has worked in the CAC region to collect, conserve and document the regions field crop PGRs whilst embarking on a program to develop the capacity of national programs to do it for themselves. What follows is a description of the current status of field crop agro-biodiversity in the region, previous efforts to safe guard it against genetic erosion and more recent efforts by ICARDA's genetic resource unit.

AGRO-BIODIVERSITY IN CENTRAL ASIA AND THE CAUCASUS

Plant Diversity Mirrors Environmental Diversity

No discussion of the region's agro-biodiversity would be complete without putting it in the context of the *exceedingly diverse natural environment*. This subject is dealt with in more depth by other papers in this volume. However, the important point to note here is that the region has an extremely diverse physical and climatic environment ranging from arid desert steppes to lush semi-tropical high rainfall zones. The five central Asian republics cover a large and landlocked area of some 400 million hectares. Much of this landmass is semi-desert, 65% could be described as rangeland, while only 7% is arable. The climate is continental and is characterized by low rainfall and extremes in temperature.

By contrast, the significantly smaller trans-Caucasian region has a very diverse physical and climatic environment. Close proximity to the Caspian and Black Seas ensures higher rainfalls and more temperate weather patterns, while the extreme topological variation creates a multitude of elevation-dependent microclimates. Figure 1 below demonstrates this diversity for the Caucasus region. It represents the agro-climatic zones based on the length of growing period and topological features.

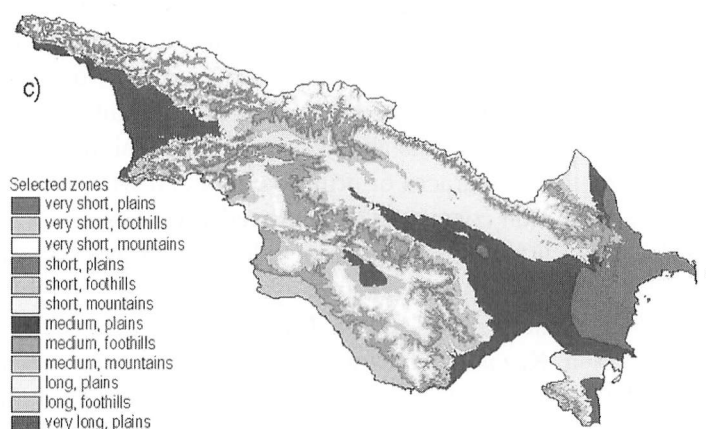


Fig. 1. Agro-ecological zone categories based on length of growing period, elevation and terrain classes for the Caucasus.

The Russian plant scientist N. I. Vavilov, who was possibly the world's most prolific plant collector, mapped out the distribution of diversity for each of the crops he studied. He hypothesized that the degree of diversity for a given species was indicative of how long the crop had been grown in that area. He then reasoned that the longer the crop had been grown there, the more diversity it would

display. He thus asserted that a crop's center of genetic diversity was where the crop had originated and had had time and opportunity to develop the diversity. A plant's '*center of diversity*' was thus its '*center of origin*' (Vavilov, 1931; 1951). Using this logic, Vavilov identified eight centers of crop origin (Fig. 2). The CAC region encompasses two out of eight (III and IV) of these major centres.

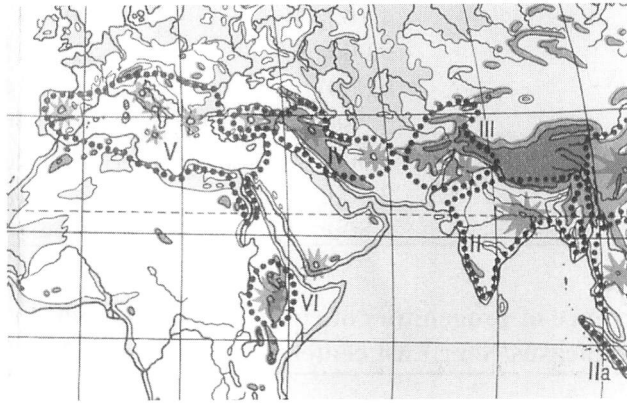


Fig. 2. Vavilov's centers of crop origin and diversity.

Among the crops that originated there are the wild relatives of *cereals* (wheat, barley, rye), *legumes* (lentils, chickpea, faba bean, pea), forage (medics, vetches, *Trigonella*, *Trifolium*, *Lathyrus*), *vegetables* (cabbage, onion, garlic, melons), *fruit trees* (almond, apricot, apple, pear, pistachio, cherry, plums, walnut, pomegranate, quince, hazelnuts, azarole, cornelian cherry, Russian olive, grape, fig, chestnut, mulberry), *industrial crops* (safflower, flax, cotton), and countless *medicinal and aromatic plants* (*Mandragora*, *Achillea*, *Glycyrrhiza*, *Valeriana*, *Ferula*). Many of the wild fruit trees form unique natural forests, important for both ecological and socio economic reasons. These species have been domesticated from the wild and selected by local populations who have patiently developed thousands of valuable varieties that are highly adapted to a broad range of climatic conditions.

More than 8,100 plant species are recorded from the region, of which 890 are endemic (Table 1). It is interesting to note here that the countries with the largest variation in elevation and terrain are also those with the greatest number of species by area. This supports the assertion that the great richness of plant diversity in the CAC region can be explained in terms of evolution processes taking place in the diverse physical and climatic conditions. Of the large number of wild species that exist in the CAC, wild relatives of cultivated species are of particular importance. Tables 2 and 3 list the wild relatives of cultivated species that are recorded in the flora of the region.

Table 1. Plant diversity and endemism in Central Asia and the Caucasus.

<u>Country</u>	<u>Plant Species</u>	<u>Endemism</u>
	-----No.-----	%
Armenia	3,555	3
Azerbaijan	4,100	5
Georgia	5,000	21
Kazakhstan,	6,000	14
Kyrgyzstan,	3,786	5
Tajikistan,	5,000	20
Turkmenistan	2,600	18
Uzbekistan	4,800	8

Table 2. Occurrence of progenitors of cultivated species within the Central Asia-Caucasus/Near East center of crop diversity .

<i>Triticum boeoticum</i>	<i>Avena sativa</i>	<i>Cucumis sativum</i>	<i>Amygdalus scoparia</i>
<i>Triticum urartu</i>	<i>Avena byzantina</i>	<i>Beta lomatogona</i>	<i>Amygdalus communis</i>
<i>Triticum araraticum</i>	<i>Vavilovia formosa</i>	<i>Beta macrorrhiza</i>	<i>Cornus mas</i>
<i>Triticum monococcum</i>	<i>Pisum elatius</i>	<i>Beta corolliflora</i>	<i>Mespilus germanica</i>
<i>Triticum paleo-colchicum</i>	<i>Cicer arietinum</i>	<i>Beta vulgaris</i>	<i>Vitis sylvestris</i>
<i>Triticum timopheevi</i>	<i>Lens culinaris</i>	<i>Daucus carota</i>	<i>Vitis vinifera</i>
<i>Triticum militinae</i>	<i>Lens nigricans</i>	<i>Brassica oleracea</i>	<i>Vitis labrusca</i>
<i>Triticum dicoccum</i>	<i>Lens orientalis</i>	<i>Allium porrum</i>	<i>Punica granatum</i>
<i>Triticum ispahanicum</i>	<i>Vicia ervilia</i>	<i>Malus orientalis</i>	<i>Ficus carica</i>
<i>Triticum persicum</i>	<i>Vicia sativa</i>	<i>Malus turkmenorum</i>	<i>Laurocerasus officinalis</i>
<i>Triticum zhukovskyi</i>	<i>Vicia pannonica</i>	<i>Genus Pyrus (25 spp.)</i>	<i>Corylus avellana</i>
<i>Triticum aestivum</i>	<i>Vicia narbonensis</i>	<i>Cydonia oblonga</i>	<i>Corylus maxima</i>
<i>Triticum spelta</i>	<i>Medicago daghestanica</i>	<i>Prunus cerasifera</i>	<i>Corylus pontica</i>
<i>Triticum macha</i>	<i>Medicago dzhavachetica</i>	<i>Prunus spinosa</i>	<i>Corylus colchica</i>
<i>Triticum vavilovii</i>	<i>Medicago hemicla</i>	<i>Prunus domestica</i>	<i>Corylus iberica</i>
<i>Secale montanum</i>	<i>Medicago romanica</i>	<i>Cerasus avium</i>	<i>Corylus imeretica</i>
<i>Secale cereale</i>	<i>Medicago cancellata</i>	<i>Cerasus vulgaris</i>	<i>Corylus cervorum</i>
<i>Secale ancestrale</i>	<i>Trifolium apertum</i>	<i>Armeniace vulgaris</i>	<i>Corylus colurna</i>
<i>Genus Aegilops</i>	<i>Onobrychis altissima</i>	<i>Amygdalus georgica</i>	<i>Castanea sativa</i>
<i>Hordeum spontaneum</i>	<i>Onobrychis transcaucasica</i>	<i>Amygdalus turcomanica</i>	<i>Genus Morus</i>
<i>Hordeum vulgare</i>	<i>Linum usitatissimum</i>	<i>Amygdalus fenzliana</i>	<i>Genus Rosa</i>
<i>Hordeum distichum</i>	<i>Cucumis melo</i>	<i>Amygdalus urartu</i>	<i>Mandragora turcomanica</i>

¹Area covering Armenia, Azerbaijan, Georgia and Turkmenistan.

Table 3. Occurrence of progenitors of cultivated species within the Central Asia-Caucasus center of crop diversity.

Species	Species	Species
<i>Triticum aestivum</i>	<i>Malus linchevskii</i>	<i>Cerasus microcarpa</i>
<i>Secale cereale</i>	<i>Pyrus korshynskyi</i>	<i>Crataegus pontica</i>
<i>Pisum sativum</i>	<i>Pyrus bucharica</i>	<i>Crataegus turkestanica</i>
<i>Lens culinaris</i>	<i>Pyrus regelii</i>	<i>Crataegus altaica</i>
<i>Vicia faba</i>	<i>Pyrus sogdiana</i>	<i>Crataegus hissarica</i>
<i>Lathyrus sativus</i>	<i>Pyrus vavilovii</i>	<i>Crataegus songarica</i>
<i>Cicer arietinum</i>	<i>Pyrus cayon</i>	<i>Amygdalus communis</i>
<i>Phaseolus aureus</i>	<i>Pyrus turcomanica</i>	<i>Amygdalus bucharica</i>
<i>Brassica campestris</i>	<i>Pyrus boissieriana</i>	<i>Amygdalus vavilovii</i>
<i>Linum usitatissimum</i>	<i>Armeniaca vulgaris</i>	<i>Amygdalus petunnikovii</i>
<i>Carthamus tinctorius</i>	<i>Prunus cerasifera</i>	<i>Amygdalus spinosissima</i>
<i>Cucumis melo</i>	<i>Prunus ferganica</i>	<i>Amygdalus ulmifolia</i>
<i>Daucus carota</i>	<i>Persica vulgaris</i>	<i>Elaeagnus angustifolia</i>
<i>Allium cepa</i>	<i>Cerasus tianschanica</i>	<i>Elaeagnus orientalis</i>
<i>Allium sativum</i>	<i>Cerasus tadzhikistanica</i>	<i>Elaeagnus songorica</i>
<i>Spinacea oleracea</i>	<i>Cerasus amygdaliflora</i>	<i>Juglans regia</i>
<i>Gossypium herbaceum</i>	<i>Cerasus verrucosa</i>	<i>Pistacia vera</i>
<i>Malus kirghisorum</i>	<i>Cerasus alaica</i>	<i>Vitis vinifera</i>
<i>Malus sieversii</i>	<i>Cerasus turcomanica</i>	<i>Fragaria bucharica</i>
<i>Malus niedzwetzkyana</i>	<i>Cerasus chodshaatensis</i>	<i>Saccharum spontaneum</i>
<i>Malus hissarica</i>	<i>Cerasus pseudoprostrata</i>	<i>Medicago sativa</i>
<i>Malus juzepczukii</i>	<i>Cearasus erythrocarpa</i>	

¹The area covering Kazakhstan, Kyrgystan, Tajikistan and Uzbekistan.

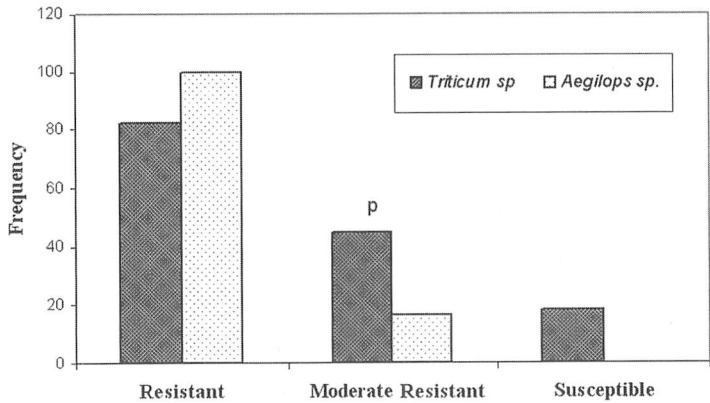


Fig. 3. Relative resistance levels to yellow rust in wheat wild relative *Aegilops* and *Triticum* species.

These wild species are an important genetic resource because they contain a wealth of useful genes that can be relatively easily introduced into modern cultivars. This was illustrated by a study conducted at ICARDA where over 500 accessions of wild wheat relatives collected in different agro-ecological zones in the CAC were evaluated for resistance to yellow rust. A total of 25 *Aegilops* and 13 *Triticum* species and subspecies, including primitive wheats, were tested under field conditions. Significant differences for resistance to yellow rust were observed among and between *Aegilops* and *Triticum* species (Fig. 3).

GENETIC EROSION

The region currently faces a difficult transition phase from a centrally controlled Soviet governance to a free market-based system. This process is fraught with difficulties that directly impact on the environment in general and the agro-ecosystem in particular. This is causing rapid genetic erosion. A significant influencing factor is the drive for food security, and thus a concentration on the domestic production of cereals. This necessitates dramatic changes in the cropping systems that were employed during Soviet times.

However, a lack of expertise and infrastructure to support the new cereal-based systems has led to poor crop husbandary and subsequent damage to the environment. For example, inadequate rotations and inputs are reducing soil fertility, causing erosion, and an increase in pests and disease. Poor drainage and increased irrigation are causing salinity, while overgrazing or under grazing is resulting in *desertification or severe deterioration of the natural rangelands*.

Some of the major causes of genetic erosion in the CAC region can be summarized below:

- A trend towards mono-cropping and a reduction in the traditional diversified farming systems.
- Introduction of uniform new varieties that replace endemic forms.
- Increased mechanization that has a having negative impact on the area under cultivation of local varieties.
- Degradation of arable land due to intensification of cropping without adequate use of rotations, soil management and other inputs.
- Salinization of soils caused by inappropriate irrigation practices.
- Pollution of the environment (water, soil, air) due to the inappropriate use of fertilizers and pesticides.
- Uncontrolled forest logging.
- Breakdown of traditional pastoral systems, resulting in both over-grazing and under-grazing, both of which change the rangeland vegetation.

- Recurrent periods of drought that are likely to become more frequent or prolonged as a result of global warming and climate change.
- Retreat of the Aral Sea, which is a major environmental disaster for the whole region. Saline dust storms increasingly affect plant ecosystems in the region.

Indeed, local botanists and international scientists have documented a massive regional loss of agro-biodiversity over the last 10 years. For example, local botanists have registered over 400 plant species as endangered in their national "Red Books". Thus the conservation and effective use of these genetic resources are of immediate and vital importance. This has been recognized and highly prioritized for action in regional meetings involving national programs and international organizations (ICARDA, CIMMYT, IPGRI, FAO) in the period from 1996 to 2003.

In a recent collection mission, undertaken by ICARDA the Vavilov Institute and national programs, an assessment of genetic erosion for pasture legume species was made in Azerbaijan and Georgia. The number of species encountered was compared with the number of species recorded by previous collection missions undertaken by the Vavilov Institute. There was clear evidence of genetic erosion having occurred over a 50-year period (Table 4). Examples such as these illustrate the clear and present need to collect and conserve the regions genetic resources.

Table 4. Genetic erosion of pasture legume species in Georgia and Azerbaijan.

Genus	Species observed	
	Previously	2001
<i>Trifolium</i>	12	8
<i>Onobrychis</i>	12	3
<i>Medicago</i>	18	12
<i>Hedysarum</i>	8	2
<i>Lotus</i>	8	4
<i>Melilotus</i>	8	3
<i>Coronilla</i>	4	2
<i>Galega</i>	2	1
Total	72	35

GENETIC RESOURCE CONSERVATION

Soviet Era

During the Soviet era, collecting, conserving and using of agrobiodiversity was headed and coordinated by the All-Union Research Institute of Plant Industry, located in ST Petersburg (VIR, renamed after N. I. Vavilov). Seed collections were maintained in the seed genebank at Kuban in Russia. Regional field collections for horticultural crops were established in Uzbekistan (focus on peach, apple, cherry, pear, plum), in Turkmenistan (pomegranate, persimmon, fig, olive), in Kazakhstan (forage and pasture crops), and in Georgia (grape), all of which were centrally controlled by the Vavilov Institute in St Petersburg.

Vavilov and his predecessors working at VIR carried out numerous collections missions in the CAC region during the 1917-1990 period, as summarized below (Fig. 4.). In 1916, Vavilov personally conducted a collecting mission to Central Asia that covered the territory of Uzbekistan, Tajikistan and Turkmenistan and which gathered more than 2000 accessions of different agricultural crops. In 1925, Vavilov and V.K. Kobelev undertook a mission to Khorezm that collected more than 1,500 samples.

Because Vavilov recognized Central Asia as one of the main centers of origin of cultivated plants, VIR established experimental stations in the region. In 1928, the Central Asian Experimental Station was opened and a more systematic research of Central Asian genetic resources began. A targeted mission on wild relatives of fruit trees was carried out in 1928-1930 in the Tian Shan region and along the margins of the Pamir. Collection of wild relatives of fruit trees continued in Uzbekistan and Turkmenistan after Vavilov. Extensive collections of vegetable landraces were carried out by Gabaev in Uzbekistan and other parts of Central Asia. Forage species were collected in Pamir in 1955 and in Turkmenistan in 1958-1959.

Between 1965 and 1990, many agricultural regions of Uzbekistan, Tajikistan, Kyrgyzstan, Turkmenistan and southern Kazakhstan were surveyed and landraces collected. In addition, collection missions were conducted in Tajikistan highlands, west Tian Shan, Alatau, Talay mountain range, and central and west Kopet Dag. During this period, some 28 collection missions were undertaken and additional 11,000 accessions of 126 agricultural crops were added to the VIR collection. These expeditions not only yielded new accessions, but also discovered new forms of cultivated species and their wild relatives and assessed the eco-geographical distribution of many important crops: for example, 128 botanical varieties of bread wheat were identified. Unique forms were also found in other field and horticultural crops (Vavilov, 1997).

The accessions collected in these missions are held at VIR in both its working collection and at the medium-term Kuban facility. There are currently 21,965 accessions from the CAC region on the Institute's books. Figures 4 and 5 provide a breakdown of these accessions per country and per type of crop.

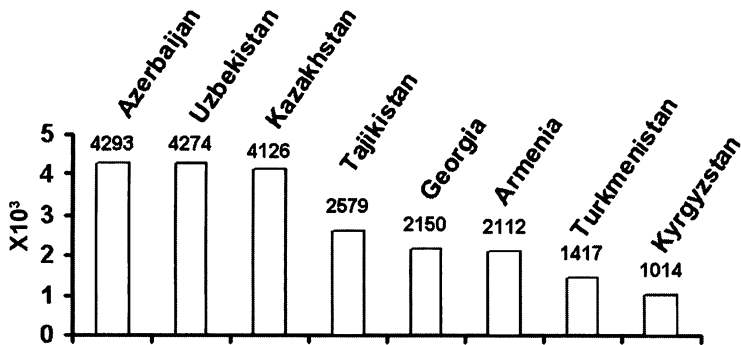


Fig. 4. Plant genetic resource accessions collected from Central Asia and the Caucasus currently stored at the Vavilov Institute.

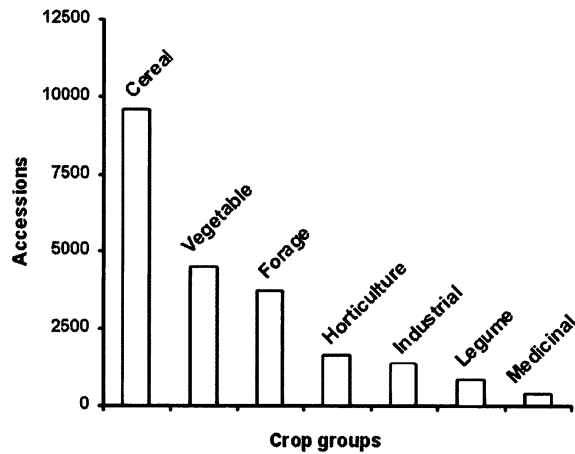


Fig. 5. Accessions (by crop group) collected from Central Asia-Caucasus regions that are stored at the Vavilov Institute.

Post- Soviet Union

State of the National Programs

After the collapse of the Soviet Union, the VIR headquarters in St Petersburg was cut off from its stations in Central Asia and the Caucasus, and its work in the area virtually ceased. This was also the case for the centrally controlled breeding and agronomy efforts in CAC. Thus, directly after the breakup, the various agricultural institutes and facilities in the region floundered without funding, direction or leadership, and are still struggling to rebuild themselves. Most countries in the region have focused what little resources they do allocate to research on the more immediate problem of developing locally adapted field crop varieties to address the problem of food security.

In this poorly-resourced environment it is easy to understand why plant genetic resources (PGR) conservation has been allocated a lower priority by national programs. Thus, there are currently no comprehensive and well resourced national programs in the region whose focus is to collect, conserve, document, characterize and promote utilization of the regions plant genetic resources. Instead, breeding programs rely on improved cultivars provided to them from international programs, or are still working with the material provided to them during Soviet times. It has thus fallen to international agencies to continue the work of preserving and utilizing the regions agro-biodiversity.

International Collection Missions

Since 1990, a number of agencies, most notably the United States Department of Agriculture (USDA), the Gatersleben Genebank in Germany (IPK), and ICARDA have conducted a series of plant collection missions in the region focusing on a variety of species. Tables 5 -6 detail the makeup of the collections from the region that reside in the genebanks of these institutions. The Gatersleben Genebank holds accessions for cereals (1279), legume (851), and forages (105) for the whole CAC region.

Developing National Plant Genetic Resources Capacity

Although there have been ongoing collection missions, and thus germplasm from the CAC region preserved in international genebanks, the long-term preservation and utilization of the region's agro-biodiversity must ultimately become the responsibility of the national programs. Thus, it falls upon the international community to facilitate the emergence of plant genetic resource programs in the area.

Both ICARDA and the International Plant Genetic Research Institute (IPGRI) have been actively seeing to development regional plant genetic resources capaci-

ty since the mid 1990s. Their first major undertaking was to facilitate the formation of The Central Asian Network on Plant Genetic Resources (CAN-PGR) in 1996. Its purpose was to coordinate activities on plant diversity conservation and use through collaborative research on set regional priorities, exchange of information and germplasm, and regional training. In 1999, three Transcaucasian coun-

Table 5. USDA germplasm holdings or accessions from the Central Asia and the Caucasus.

Country	Cereals	Legumes	Forages
		No.	
Armenia	137	7	1
Azerbaijan	35	1	0
Georgia	303	2	17
Kazakhstan	88	8	6
Kyrgyzstan	3	3	0
Tajikistan	35	1	0
Turkmenistan	63	0	0
Uzbekistan	79	55	1
Total	743	77	45

Table 6. ICARDA's germplasm holdings or accessions from the Central Asia and the Caucasus.

Country	Cereals	Legumes	Forages
		No.	
Armenia	320	162	55
Azerbaijan	605	253	120
Georgia	325	135	60
Kazakhstan	268	5	129
Kyrgyzstan	68	51	95
Tajikistan	206	383	57
Turkmenistan	25	62	80
Uzbekistan	332	110	19
Total	2149	1161	615

tries, namely Azerbaijan,

Armenia and Georgia joined the Network and it was renamed into Central Asian and Transcaucasian Network on Plant Genetic Resources (CATCN-PGR). In addition to the CATCN-PGR, nine Regional Crop Thematic Working Groups were established in the framework of this regional cooperative mechanism.

Despite this reasonably well thought-out conceptual and organizational framework, this initiative has had limited impact at a practical level. After some investigation by ICARDA's Genetic Resource Unit on why this Network/Working Group approach has not worked in the CAC region, the following reasons became evident and were used to shape the strategies employed by ICARDA in its capacity development work:

- Most agricultural institutes in the region are severely limited financially, as well as by a lack of manpower. Thus, in many cases, they simply do not have the people or finances to divert to plant genetic resources activities. This is summed up by the comments of a national plant genetic resources coordinator and deputy of an Agricultural Academy who was answering the question as to why there is little plant genetic resources work being done in his country. "When I cannot afford to pay a scientist his salary and he still comes to work anyway, he is doing it out of devotion to his chosen area. How then can I ask him to turn around and do something different like plant genetic resources work? Furthermore, if I can hardly find the money to pay my staff, where will I find the money to do plant genetic resources activities?"
- The Thematic Working Groups were composed of people who generally have no commitment to plant genetic resources work because they are already employed, usually on very small salaries, in another area and simply do not have the time.
- There were no agencies or even people within institutes whose sole focus was plant genetic resources' conservation work.
- There is a general lack of experience in all aspects of plant genetic resources, work.
- Plant genetic resources work was generally poorly understood in the region.
- There is a general lack of young scientists who are willing to work in a non-traditional field. Most of the scientists who work in the agricultural sphere in CAC are plant breeders who are near retirement age and have little willingness to move into a new direction.
- Due to a lack of understanding about what plant genetic resources conservation is attempting to achieve, there was a general lack of commitment on the part of policymakers to invest scarce national resources towards plant genetic

resources work.

Thus, although many recommendations and undertakings are made in the Central Asian and Trans-Caucasian Plant Genetic Resources network coordination meetings, in reality and in general, the national programs simply do not have the human resources and/or finances to redirect into plant genetic resources work, and so the output from the investment made in the CATC plant genetic resources network strategy is negligible.

ICARDA's Role

Supported by funding from various donor agencies, ICARDA, has employed a three-pronged approach to its plant genetic resource work in Central Asia and the Caucasus. First, it supports direct action to *collect, conserve, document* and *evaluate* the current agro-biodiversity. Thus, there is a consistent and ongoing plant genetic resources program in the region to offset the ongoing genetic erosion in the area.

The second and interlinked strategy has been to develop the capacity of national programs so that they are able to undertake the collection, conservation documentation and evaluation of plant genetic resources for themselves. The approach ICARDA has taken is to foster and support the development of small genetic resource units within each country composed of junior scientists who will undertake the actual "coal face" work. Thus, the various training, human resource development and coordination efforts have been focused towards the members of these units and to some extent towards the institutes where they are situated. Plant genetic resources focused projects, such as those supported by Australian Center for International Agricultural Research (ACIAR), have supplied funds to support the activities of these units.

The third approach has been to garner lasting support and commitment towards plant genetic resources conservation and utilization at the policy-making level by raising the awareness of the importance of plant genetic resources conservation. This is done in parallel with the two more grass- roots strategies. In fact, these activities support one another. When policy-makers see that the genetic resource units are undertaking activities with tangible and useful outputs they are more inclined to invest in supporting an ongoing plant genetic resources' conservation and utilization program well after the life of ICARDA-run projects.

In fact, this process is well underway. In Kazakhstan, for example, the government has earmarked 10 million dollars for the development of a high tech genebank, while Azerbaijan has secured a World Bank loan to support the establishment of a plant genetic resources institute. Table 7 details some of actions that ICARDA has facilitated since 1998. These activities have laid a solid foundation in terms of local capacity to build-upon in the long term.

Table 7. Recent ICARDA/Genetic Resource Unit activities in Central Asia and the Caucasus.

Activity	Description
Development of national PGR units.	Development of national genetic resource units to undertake practical PGR conservation action.
Inventories of <i>ex-situ</i> seed collections	PGR to undertook inventories of their countries <i>ex-situ</i> seed collections.
Coordination meetings	Annual regional coordination supported by coordination meetings to promote PGR conservation region development
Scientific visits	Key personnel supported to make numerous scientific visits for training and program coordination
Training	Scientists (24) trained to support PGR work. English language, collection mission procedures, database management, using GIS tools, web-page development, genebank management, field characterization methods, molecular characterization, and general computer skills.
Provision of capital items	Computers and associated equipment, a collection mission vehicle, GPS units, seed storage packets, cooling and shelving for seed storage.
Collection missions	Separate missions in all countries, collected over 2000 accessions of crop wild relatives, landraces and forage, pasture and range species.
Field and laboratory characterization and evaluation or CAC material	Accessions from CAC evaluated for useful traits at ICARDA.
Technical backstopping for seed storage facilities	ICARDA attracted funding and providing technical expertise to upgrade the storage for CAC largest <i>ex-situ</i> collection based in Uzbekistan. Facilitates development of storage facilities (Armenia, Azerbaijan, Georgia, Krgyzstan and Tajikistan).
Web page development	Networking tool to promote conservation, funding opportunities and highlight current conservation efforts in the region ICARDA facilitated the development of a web-page on PGR in CAC region/countries.
Funding proposal development	ICARDA personnel in collaboration with national programs have developed of funding proposals, of which now support the current capacity. Development and conservation work in the area.

One of the outcomes of the above activities is an increased awareness by decision-makers in the region of the importance of plant genetic resources, conservation and an increased willingness to invest in it. The following summarizes commitments made by national programs to plant genetic resources conser-

Table 8. Genetic resources' action programs.

Country	Actions
Armenia	Unit established at the Botanic Institute. National inventory 100% complete.
Azerbaijan	Establishment of Plant Genetic Resource Institute. Plans well advanced to build seed storage facilities.
Georgia	Units established and active. Center established at the Farming Institute.
Kazakhstan	National plant genetic resources policy developed plant genetic resources unit established. Government Funds committed to modern storage facility.
Kyrgyzstan	Unit and Center established, Seed storage facility being built.
Tajikistan	Unit and Center established, Seed storage facility being built.
Turkmenistan	Unit established. Department established in the Cereals and Legumes Research Institute.
Uzbekistan	Uzbek Research Institute of Plant Industry supported by the government to continue its PGR work. USDA aid money used to upgrade the UzRIPI storage facility.

vation and utilization:

Genetic Resources Conservation and Utilization- the Future

Despite these encouraging signs of an emerging commitment and willingness to invest by national programs, outside support is still necessary to continue to the capacity development, build seed storage facilities and to facilitate the emergence of national policy and strategy with a long term focus. Figure 6 details a potential

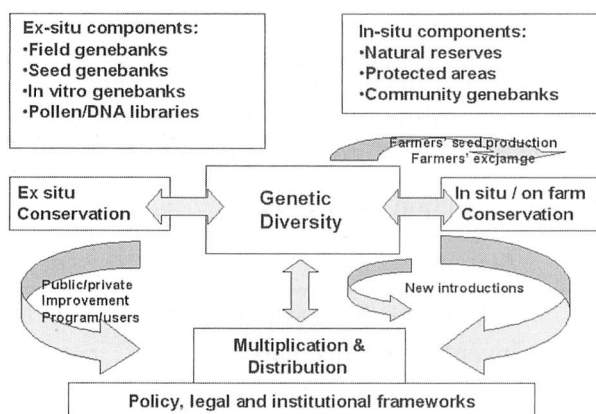


Fig. 6. Integrated conservation and use strategies for plant genetic resources in the Caucasus region.

scheme for an integrated regional approach.

Areas where intervention will be necessary to promote long-term plant genetic resources conservation and utilization are suggested below:

Table 9. Long-term genetic resources interventions.

Intervention	Description
Moves towards sustainable agriculture	Develop means to support sustainable agricultural production, negative impacts on natural biodiversity are minimized.
Bioregional perspective	Adoption of a broader perspective of agriculture to capitalize on shared regional opportunities offered
Inventory/ information sharing	Survey, inventory and disseminating information for enhancing agricultural development.
Genetic resource conservation	Develop national <i>ex-situ</i> storage facilities.
On-farm management of Plant Genetic Resource	Enhance on-farm management of genetic diversity (land races and traditional breeds of livestock) and ways to manage these in a more efficient and durable way.
Broadening the genetic basis of crops and livestock	Efforts are needed to widen the genetic base of modern cultivars, usually very narrow
Conserve biodiversity in natural Ecosystems	Natural and semi-natural ecosystems contain wild species, races, and populations of great importance for food and agriculture, develop efforts to strengthen maintain of these ecosystems across the region.
Broaden cultivated crop portfolio	In recognition of the economic potentials offered by the vast ABD in CAC region, efforts should be direct efforts to widen diversity of farm crops/breeds to promote agricultural sustainability.

SUMMARY AND CONCLUSION

The Central Asia and the Caucasus region encompasses two major centers of crop origin and diversification. As such the region is home to a wealth of agrobiodiversity that is both regionally and globally important. However, this diversity is under extreme threat due to genetic erosion being caused by a variety of factors such the rapidly changing agro-ecosystem brought on by the breakup of the Soviet Union.

Due to the difficult post-Soviet transition phase being experienced by the countries in the region national programs are not currently in a position to conserve and utilize their plant genetic resources therefore international intervention and support has been needed to maintain the plant genetic resources work begun by the Vavilov Institute during Soviet times. ICARDA has undertaken a practical approach to the development of plant genetic resources work in the region that has included *direct action*, *capacity development* and *raising the awareness* of regional policy makers.

Despite significant progress, further support and intervention by international bodies is required to build upon the achievements made in recent years and to support the fledgling national plant genetic resources programs.

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Livestock Production in Central Asia: Constraints and Research Opportunities

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ABSTRACT

Livestock production in Central Asia is in a severe crisis. The dissolution of Soviet markets, deterioration of production - supporting services, fragmentation of land and livestock tenure, cessation of seasonal grazing; and a poorly supported research system characterize the current production scenario. This is reflected in low production levels, production stagnation, low returns per flock/herd, increased poverty, and nutrition deterioration. Concurrently, the resource base is deteriorating progressively. Agricultural research offers themes of scientific interest with direct implication for the improvement of livelihoods. Topics in socioeconomic research include the exploration of market opportunities and appropriate policies, and characterization of production systems and their interactions. Challenging research to assess genetic diversity is attractive and a key to match breeds to market and production potentials, diversification and diversity management. Equally attractive is research on range management, and forage and animal production, targeting appropriate natural resource management, sustainability of production systems and market opportunities to improve farmer's income.

INTRODUCTION

The rangelands of Central Asia comprise over 250 million ha (FAO, 2001) distributed through diverse agroecologies, most in areas with rainfall below 250 mm-yr⁻¹, which significantly support livestock production. The region, including five countries, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, harbors a wealth of genetic diversity, with indigenous and synthetic breeds adapted to the prevailing harsh and dry environments. There are approximately 32.6 million small ruminants that are part of this diversity also distributed in the various agroecologies of Central Asia (FAO, 2001). Both rangelands and livestock have been exploited since time immemorial, though more systematically during the Soviet Union. These resources still contribute importantly to the livelihood of the rural economies of all countries and often are the sole source of income for poor producers.

The shift to a new economic system from a centralized economy after the breakdown of the Soviet Union, at the start of the 1990s, changed the production context dramatically with severe impacts on livestock production sector in general and the small ruminant production sector in particular (Suleimenov and Oram, 2000). The shift involved the application of reforms, more intensively in Kazakhstan and Kyrgyzstan than in the remaining countries, leading to the emergency of new production systems that thrive under new constraints and economic difficulties.

In this paper, the main problems characterizing the small ruminant production systems and urgent areas identified by ICARDA as research opportunities to help emerging farmers to improve their income, are outlined.

PRODUCTION ENVIRONMENT CHANGE

Tenure Change

Several changes occurring at the end of the Soviet regime negatively influenced the livestock production sector of Central Asia. This included the application of reforms, in particular involving the privatization of land and livestock. The privatization of resources was effective but resulted in the fragmentation of large holdings, such as Cooperative and State-owned enterprises, into small and unproductive holdings, mostly landless and possessing fewer animals. Figure 1 shows the distribution of tenure at the end of the Soviet Union in 1990 and after 10 years in 2000. Following the Soviet tenure structure, at the beginning of the 1990s land was concentrated in mostly large landholdings with a smaller population of smallholders consisting of employed people having few sheep or cattle in their backyards. Ten years after, this contrasted with the emergency of new forms

of tenure and the dramatic increase of smallholdings (Schillhorn van Veen, 1996; ICARDA, 2000). Notice that individual farms increased more in the countries with a more intensive application of reforms.

The emerging farms include cooperatives, individual farms and household farms. The cooperative farms are various kinds of joint stock companies with the involvement of government, particularly in Uzbekistan and Turkmenistan. Individual farms are registered as legal entities owned by individuals. Unlike western types of family farms where the farmer is simultaneously owner, manager and main laborer, the owner of an individual farm in Central Asia usually acts as farm manager with a group, sometimes large, of hired labor for farm operations. The size of individual farms varies, normally fitting into a medium size operations, but could be as small as a household or as large as a collective farm (ICARDA, 2000; 2001a).

Kyr=Kyrgyzstan; Kaz=Kazakhstan; Uzb=Uzbekistan; Tur=Turkmenistan

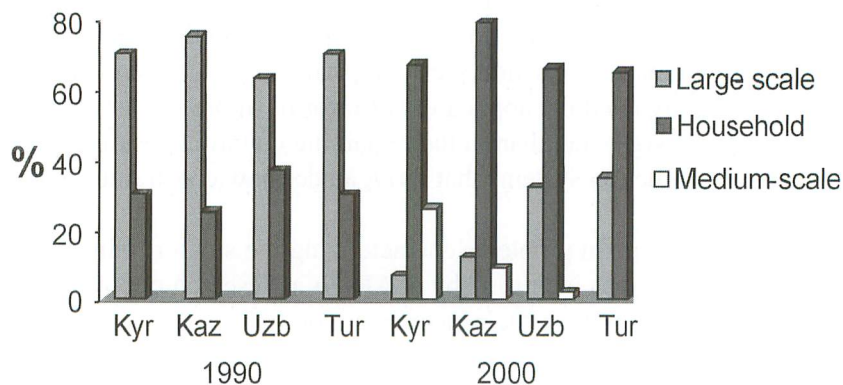


Fig. 1. Distribution of production systems in relation to share of small ruminants at the end of the Soviet Union in 1990 and 2000.

Large scale farms still play an important role in livestock production in countries with gradual reforms, while they almost were substituted by household farms in countries with more liberalized economies. This structure has been usually ignored and scientists disregarded small-scale farms because they were more familiar with large agricultural enterprises and household or small-scale farms did not exist as farms in Soviet times (Sansizbay, 2003).

Market Collapse

Another equally important change paralleled the reforms. The collapse and dissolution of the large Soviet market that formerly absorbed all wool and pelts produced in Central Asia left limited opportunities for farmers to market their

products. In a recent assessment, Mueller (2000) found that quality of the wool was poor and with little chance to compete with highly competitive producers such as Australia and New Zealand that offer better quality wool at lower prices and dominate the international trade. Current prices paid for wool are low (ICARDA, 2002) and did not improve since the early 1990s (Bloch, 1997).

The pelt production sector, particularly producing Karakul pelts, encounters only a market with rapid saturation to target. In addition, marketing infrastructure and strategies prevent an effective capture of market possibilities. In Uzbekistan, the currently owned government factory for pelt processing and marketing finds difficulties to pay back farmers, due to lack of cash. These problems are aggravated by the production scale problem inherent in current smallholdings. Even though the market could offer solid opportunities for marketing, the returns per flock basis of traditional products such as wool, skins or pelts, offer little incentives in view of the small flock size.

Interestingly, market options, including a demand created by traders that move the products to China (Mueller, 2000), occurred in relation to goat's mohair and particularly cashmere production, however subject to unfair intermediation. Meat and milk are highly demanded in local markets, particularly in large urban centers that are also concentrating the population of migrants from rural areas. Local markets develop in a disorganized manner and often are also subject to unfair intermediation and poor forms of trade (Schillhorn van Veen, 1996; ICARDA, 2001a).

Production Supporting Services and Organization Change

The application of reforms was also accompanied by the deterioration, and in some cases dissolution of production organization and support services, and the lack of funding for modernized research and technology transfer organizations. Though farmers are usually educated and some have working experience and knowledge in animal and agricultural production, their knowledge is confined to large-scale production, such that low-input small-scale production technologies and strategies are not completely known.

Lastly, credit or any form of financial support to production is not widely available. In general, a culture of borrowing money was not developed during Soviet times, and companies never financed the purchase of farm assets. Thus, credit is not available or accessible, and farmers are supposed to pay the total cost of machinery or agricultural inputs in cash. This results in limited availability of machinery, equipment and farm inputs. There have been efforts made by the different countries to develop some forms of credit, but these programs failed to be effective because they requested unaffordable guarantees or interest rates (ICARDA, 2001a).

Differential Application of Reforms

As already indicated, the reforms were applied differently across countries leading also to less impact in those countries that moved more conservatively. While Kyrgyzstan and Kazakhstan applied the reforms and suffered from the consequences more acutely, changes in Turkmenistan and Uzbekistan were relatively moderate. Figure 2 is an attempt to illustrate the intensiveness of reform application, taking Kyrgyzstan as an example of a country applying the reforms most intensively (ICARDA, 2003). This gradient provides an interesting economic design by accident that could be capitalized in assessing the sequel of changes on the livestock production sector in the region. This assessment is coincident with the findings of Kerven et al. (2003).

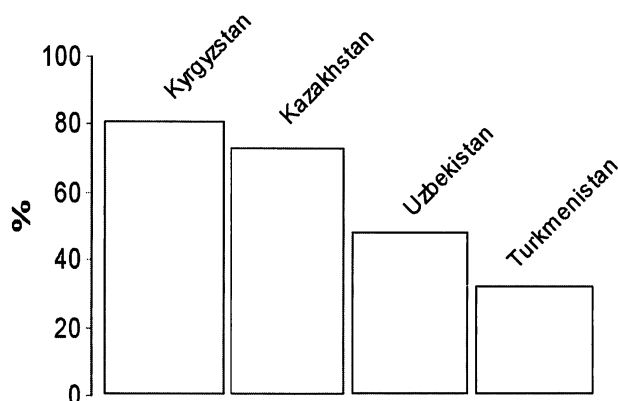


Fig. 2. Degree of reform in Central Asian republics after the fall of the Soviet Union.

IMPACTS OF LIVESTOCK PRODUCTION CHANGES

Small Ruminant Population Decline

The collapse of markets lead to production stagnation and farmer's frustration. Having no options to generate income, farmers begun to sell progressively their animal stocks. This translated into a dramatic animal population decline. Figure 3 shows the population changes of small ruminants after the end of the Soviet period in the 1990s, relative to the population in 1990 taken as a population base.

The population declines in Kyrgyzstan and Kazakhstan reached alarming levels. By 1998 the Kazakh populations of small ruminants decreased by nearly

70%, from 35 million heads in 1990 to barely 10 million heads in 1998 (FAO, 2001). While the decline was similar in proportion in Kyrgyzstan (Schillhorn van Veen, 1996), the decline in numbers of animals was comparatively less due to a smaller animal stock in that country. This contrasted with rather minor changes occurring in Uzbekistan and Turkmenistan as a reflection of more conservative applications of reforms and subsidies. Tajikistan was the country with more vulnerable economy and more poverty indices at the end of the Soviet Union, a fact that aggravated the production scenario even though the application of reforms were not as intensive as in Kazakhstan and Uzbekistan.

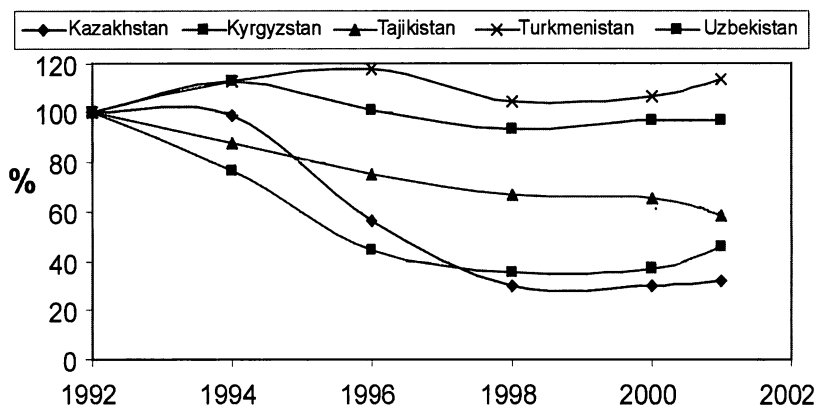


Fig. 3. Relative population changes of small ruminants in transition period.

Inadequate Grazing and Winter Feeding Costs

The striking problem is the failure of emerging production systems to adequately and timely use rangelands - the cheapest feed source. Large flocks/herds of small ruminants were formerly managed by different seasonal and rotational grazing strategies, some involving the movement of flocks through several thousand of km in the year to graze seasonal ranges. Nowadays the movement of flocks by small producers is virtually impossible, as this requires capital and special arrangements that smallholders simply cannot afford. As a consequence animals roam around the villages and nearby ranges causing intense degradation nearby villages and undergrazing of remote ranges.

The consequence of overgrazing and undergrazing, illustrated in Figure 4, shows the decreased productivity around villages even in spring, the season with more fodder availability (about 175 DM kg ha⁻¹) as opposed to 1.5 times more (260 DM kg ha⁻¹) at 6 to 12 km away and 2.5 times in remote ranges (about 430 DM kg ha⁻¹) (ICARDA, 2001a). Such a condition applies to all countries, even

those where the reforms were not applied in depth and is more critical during fall and winter. The consequence of this is direct land degradation and the rise of conflicts in the farm environments due to increased competition for resources (ICARDA, 2002).

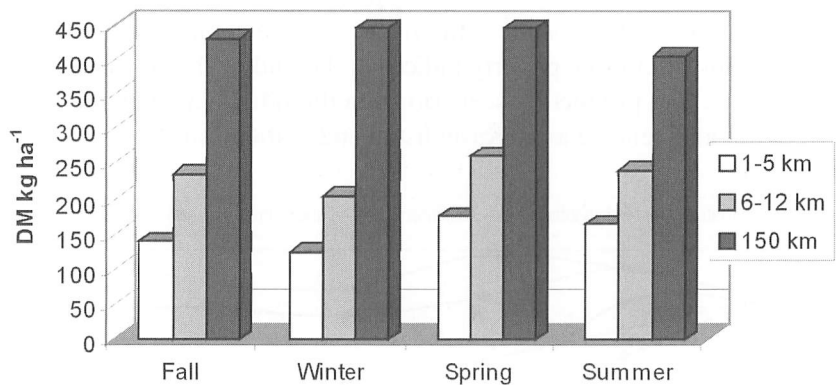


Fig. 4. Standing biomass around villages and in more remote areas in Berlik, Zhambyl District, foothill steppes of the Alatau Range, Kazakhstan.

A generalized problem identified by all our studies conducted in the region involves high feeding costs and scarcity of fodder during winter (ICARDA, 1999, 2000, 2001a, 2002), which corroborate former assessments (Kerven and Behnke, 1996; Schillhorn van Veen, 1996). This is because of farmers failing to store fodder stocks through the harvesting of forage or range fodder. This operation requires adequate machinery and infrastructure. Machinery is mostly in a state of obsolescence, whereas available infrastructure, mostly built to suit large farm operations, was unsuitable to meet the needs of smallholders. Large barns and silos, part of the inventory of the Soviet large landholdings, were systematically dismantled; these losses probably amount to several millions of dollars.

The lack of fodder seeds and a strategy to produce them is a problem still to be resolved. Some farmers of ICARDA's on-farm network in Kazakhstan, Turkmenistan, and Uzbekistan were using seed stocks distributed back in the early 1990s (Saamurat Kheremov, personal communication, Turkmen Agricultural University, 1999; Igor Massino, Livestock Research Institute, Tashkent, 1999). During the Soviet Union time, farms grew forages both under irrigation (i.e., alfalfa) and on rainfed cropland following defined plans for livestock and feed production. After the end of this period, in some countries, governments still maintain crop production under control leaving the livestock sector with no support, which resulted in most cases in complete stoppage of forage production.

In countries with more liberal economies, the former state farms also are uninterested in forage production, as livestock production is less profitable than crops.

With less feed resources to feed their animals, farmers are left with no choice but to purchase feeds, particularly during winter. This has an impact on the production costs as reflected in Figure 5 in different categories of farms in Kazakhstan, and Uzbekistan (ICARDA, 2002). In Kazakhstan, independent farmers having allocation of arable land can produce their own reserves for winter, and in Uzbekistan sheepherders can access feed of the cooperatives for their own animals. Notice that for householders, the majority of livestock producers in Central Asia, the provision of fodder costs accounts for a considerable part (50 to 63%) of farm costs.

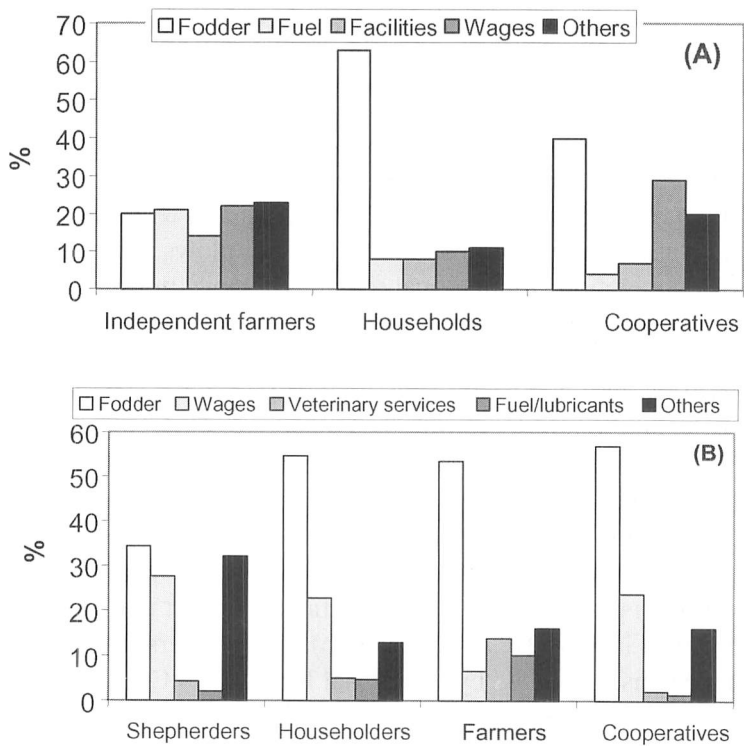


Fig. 5. Incidence of farm cost expenditures in different farms of Kazakhstan (A) and Uzbekistan (B).

Inadequate Health and Lack of Breeding Schemes

Other problems involve the emergency of new animal health problems in the region. The lack of reliable epidemiological systems and assessments cannot estimate the magnitude of this problem. The health control is provided by the government, but it is insufficient to cover the existing demand and its associated costs are reflected in farm costs (Fig. 5) (ICARDA, 2000). Furthermore, the collapse of breeding programs is determining serious risks to the integrity of genetic resources because of indiscriminate crossing among breeds (Iñiguez, 2004) or the disappearance of breeds or the wrong targeting of breeding goals (Schillhorn van Veen, 1996).

The combination of the former problems and constraints reflects in low production levels, which in turn lead to increasing levels of poverty and rural migration, and a further decline in consumption rates due to low purchasing power.

RESEARCH OPPORTUNITIES

Agricultural research oriented to solve problems, and leading to improve the income of farmers, is urgently needed in Central Asia and will play an important role in its reactivation and modernization. ICARDA follows this orientation and works in close cooperation with national research organizations. Emphasis should be given to develop a research framework acknowledging and involving current production systems (Schillhorn van Veen, 1996). The National Programs have received little support by the governments, as other urgent social and economic issues have captured the priority during the recent past. Governments, however, are responsive to efforts leading to collaborative research reflecting the importance that is given to this area.

Several organizations have started successful research activities in livestock production in the region. Among others, the United States Department of Agriculture (USDA) provided the first international support to ICARDA to start a research undertaken in 1996 (ICARDA, 2001b). The Universities of California and Wisconsin-Madison, funded by the Global Livestock - Collaborative Research Support Program (CRSP), also joined in these efforts and have devoted research efforts to livestock production (SR-CRSP, 1996).

In the specific development of the Feed and Livestock Production in the Steppes of Central Asia project, ICARDA has identified the following research topics that needed urgent attention (ICARDA, 1999), would have direct impact on the livelihood of farmers and also offered attractive subjects for collaboration:

- Emphasis on a new research approach oriented to the emerging production and farm environment
- Types of production systems, constraints and interactions among them in relation to use of natural resources, livestock management, and marketing.
- Winter feeding and enhancing the feed base
- Production orientation and diversification to target market opportunities
- Assessment of biodiversity and access by farmers to improved germplasm
- Institutional strengthening

These research topics were coincident with priorities identified earlier (SR-CRSP, 1996). It is obvious that research not only should be concentrate on these issues. There is a range of possibilities where adaptive research and technology transfer are just required and other areas where strategic and basic research could take place. To illustrate the directions of the research objectives and guiding results, examples were taken from the implementation of ICARDA's research agenda under the project already cited above that was supported by the International Fund for Agricultural Research (IFAD) in Central Asia.

New Research Approach Orientation

Livestock research in Central Asia has been oriented not necessarily to solve problems, or interact with farmers, or to target market opportunities. There is a need of a new approach where *the focus should be the farm environment and its inherent relationships*, particularly those involving markets. New methodologies of participatory and community-based research that facilitate the work with resource-poor producers with more difficult constraints to dealt with are lacking in the region and should receive priority while training scientists. The current production scenario and the absence of technology transfer systems urge also the development of strategies to train farmers, particularly raising their awareness about possibilities for better marketing of products as well as for use of natural resources. In this regard, the interaction of research with development projects could be instrumental.

The change of approach may not be straightforward but proven to be possible if considerable effort is placed into national research programs, such as in the work conducted by ICARDA and collaborators in the region. However, an adequate level of training to fit into this approach and a critical mass of supporting socioeconomic scientists are required.

Socioeconomic Research

The gradient in the application of different reforms gave place to a range of types of farms that in most cases co-exist in the same production niches. A range of positive and negative interactions exists with direct ramifications in the livelihood of the farming systems that need to be accounted for urgently. In countries with more intense reforms (Kazakhstan and Kyrgyzstan), the balance is still leaning to the negative side and detrimental to the stability of rural society due to gaps in the social structure. For instance, householder flocks, as noted before, degrade ranges around villages and eventually in the land of larger enterprises. However, awareness of the need of community action is on the rise at both levels. In countries where reforms were applied gradually (i.e. Uzbekistan and Turkmenistan), the balance is a little more in the positive side because of the incentives created by the large farms (cooperatives) to household cooperative members. However, if the household population is large the balance could be negative and lead again to conflicts in the use of resources (ICARDA, 2002). Positive complementarities and community action could be exploited and give place ways out to production constraints, particularly with regard to the use of land resources and marketing of products.

Winter-Feeding and Feed Scarcity Problems

As already underlined the difficulties confronted during winter-feeding and the scarcity of fodder through the year are considered the most limiting factors for small ruminant production that reflect on productivity and low yields. An approach to overcome these problems is not straightforward and involves, among others, complex issues of socioeconomic nature, degradation of resources, production organization and policies,

Suitable Utilization of Range and Storage of Feed for Winter

This should be the first approach to be followed to benefit from the cheapest source of feed. Access to remote ranges and also to winter ranges should be looked upon, however the limiting factor is that most of farmers cannot afford the arrangements involved. The solution could be found in inspecting positive interactions among production systems for resource management and community action to promote associations for collective range grazing such as that leading to the formation of a consolidated or *mobile* flock

One example is found in the work conducted in Kazakhstan in collaboration with the Farmers' Federation of Kazakhstan (ICARDA, 2002). In 2000, community action was initiated in the community of Berlik, Zhambyl District, a representative area of the foothill steppes of the Alatau Mountains that dominate the region.

The village area is heavily overgrazed with evident processes of erosion while remote ranges are unused. The village is mostly composed by smallholders having few heads of livestock, including small ruminants.

Discussion started with 24 farmers to put in practice the consolidation of a flock, the mobile flock, for collective grazing projected for a period of 7 months in distant ranges, at least 15 km from the villages. This involved discussions of the ranges to be grazed, the availability of wells and the potential areas of conflict with other farmers also grazing remote ranges to which they may have the right to access to. The important issue was the unit cost per sheep to be managed. An estimated cost of 450 Tenge per animal, which represents 12 to 15% of the price of an animal, was calculated as the grazing fee.

In 2001, the herd was operational and under production monitoring. A total of 23 of 110 families entrusted their sheep and goats (from 1 to 70 animals per family) to Abdalla Sarsenbiev, the shepherd. On April 20, when the herd moved to a remote range, the total number of livestock amounted to 593 heads: 305 adult sheep and goats, and 288 lambs and kids. The main part of the sheep flock consisted of Kazakh fine-wool animals. The animals were finally moved to the mountains for summer grazing. On June 29, the lambs were weighed for the second time. The average live weight was 31.8 kg (23 to 35.5 kg). The shepherd predicted that no weight gains would be expected in July and the beginning of August due to the intense summer heat, but further gains in live weight would occur from the end of August till the end of October. By this period, the lambs weighed acceptable weights 40 to 45 kg, regardless of the date of lamb's birth and, more importantly, the lambs were marketed and generated income.

The results of autumn weighing confirmed the shepherd's opinion. The point here is that sheep are utilizing the range resources and the areas around villages will recover and the degradation process eventually will revert.

Fodder Production Enhancement: Irrigated and Rainfed Areas

Fresh or stored fodder is currently a profitable commodity in all Central Asia. It is not uncommon to see, along the roads and in the outskirts of the main cities, trucks with a load of hay of alfalfa or cultivated forage that are sold rapidly. Individual farmers and medium size farmers having some allocation of land and access to irrigation or to rainfed areas are beginning to realize this opportunity. Minimal investment in improving the access to irrigation could notably boost the production of fodder, make it available, and eventually open alternatives for sharing its utilization with householders often with no chances to cultivate forages because of lack of land, under special arrangements (ICARDA, 2002). Ample research possibilities to target the production of legume and non-legume species are found. Furthermore, as in Uzbekistan and Turkmenistan, the cropping of

wheat and cotton requires adequate rotations to avoid monoculture and new forms for intensive production.

Maximizing the opportunity to access irrigation for fodder production: In the Baykozon farm, Uzbekistan, in collaboration with researchers at the Livestock Research Institute of Tashkent, research trials have been targeting intensive production of fodder for better returns to irrigation access. Boykozon is a dairy cattle production area with potential to produce cultivated fodder also required by sheep during winter. A rotation of forage mixture (triticale + oat + fodder pea) planted in the fall and harvested at the end of April followed by maize for corn and silage, demonstrated the possibility to produce 15.7 tons of DM ha⁻¹, in addition to 5.8 tons of corn grain ha⁻¹, as compared to only 9.5 tons of DM ha⁻¹ produced by the traditional system based on only spring planted corn cropping.

Smallholder strategies for fodder production in rainfed areas: In collaboration with the Kyrgyz Livestock Research Institute in the highlands of Kyrgyzstan, legume-cereals crops were successfully on-farm tested at two sites in the highlands for improving winter-feeding in 2001. These involved: (a) 20 ha of sainfoin planted along with barley as a cover crop in Kokjar, yielding 40 tons of barley grain and 30 tons of barley straw and sainfoin hay, in addition to 700 kg ha⁻¹ of stubble; and (b) 10 ha of alfalfa in Kemin using barley as a cover crop, yielding 4 tons of barley grain and 500 to 600 kg ha⁻¹ of alfalfa stubble grazed in autumn. The main point here was to adjust technologies formerly used extensively by large holdings to the possibilities of small-scale holders. The mixed crop has captured the attention of farmers who followed this practice in 2002 (ICARDA, 2002).

Using Non-Conventional Production of Fodder

The use of desert halophytes produced with drainage water dumped in the deserts of Turkmenistan is given as an example. In the farm of Mr. Sazak Imamgulyev at Yzgant, Turkmenistan, in collaboration with the scientists of the Research Institute of Deserts Flora and Fauna, a less conventional irrigation production scheme using drainage water, otherwise dumped in the deserts of Turkmenistan, was followed. By July until the start of the rains at the end of the year, the range in this area consists mainly of ephemeral vegetation that grew in spring and early summer and that was heavily grazed by sheep. This period is important for the mating of sheep, the main livestock species, and the onset of the last third of pregnancy. Turkmen farmers rely heavily on the availability of range fodder at this time.

Figure 6 shows that the standing consumable biomass available during the fall, measured in two ranges of Yzgant farm, is below 20 kg ha⁻¹ and could be considered negligible for rational feeding purposes. During this critical period of water

scarcity, the use of drainage water allowed the production of halophytes in 2.5 ha of degraded range with evident process of salinity. By September 2001, when little biomass was available in the range, this made 7.86 of *Climacoptera lanata*, 8.75 of Annual *Atriplex*, 6.14 of *Suaeda altissima* and 1.27 of Perennial *Atriplex*. This finding opens possibilities for adequate utilization of a considerable volume of unused drainage water provided that salinity problems will not be increased nor undegraded areas used for this purpose.

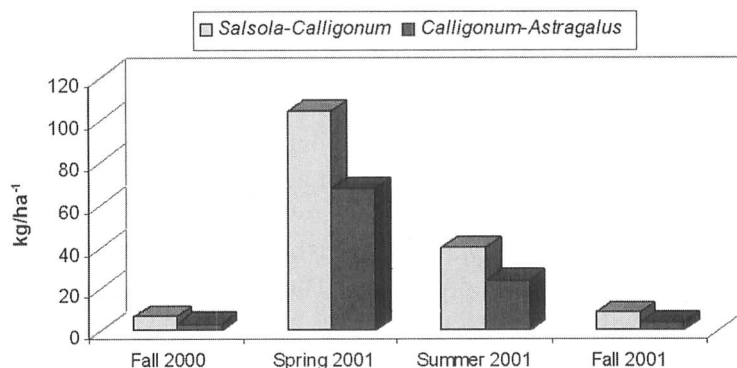


Fig. 6. Consumable biomass in two types of ranges, *Salsola-Calligonum* and *Calligonum-Astragalus*, in Yzgant farm, Central Karakoum, Turkmenistan.

Utilization of Byproducts and Unconventional Sources of Fodder

Several agroindustrial byproducts and crop residues are not fully utilized in animal feeding, as the integration of livestock with crop production is not effectively happening, except in certain areas of the region. This is partly due to inadequate information and partly to farmers' lack of knowledge in the use and the means of using these resources. For instance, crop residues such as cotton widely practiced in West Asia could provide substantive feeding options to livestock farmers in Uzbekistan and Turkmenistan. However, research should consider issues of potential toxicity by chemicals or the levels of gossypol remaining in the residues in relation to the varieties used in both countries.

Range plants are harvested annually to suit the needs of winter-feeding. Exploration on the feed value and improvement of the feeding value of these plants, i.e., with urea treatment, is worthy. The University of California through the GL-CRSP started research in this direction. Likewise, the exploration of the value of unconventional feed resources deserves attention as in the case of

mulberry in view of its importance in Uzbekistan. Some production issues could be applicable to all Central Asian countries, while other may be only valid for a given country and eventually a region within this country, as in the case of Mulberry production.

Exploring the use of mulberry trees for improving feeding systems: In the ongoing research collaboration with scientists at the Karakul Research Institute of Uzbekistan, Samarkand, the use of mulberry leaves in livestock feeding systems was considered. The assessment of the availability of this feeding material indicated that there are about 800 specialized silk farms in the country, including about 33,000 ha of mulberry (8 million trees), in addition to 93 million trees along the roads or dividing cropping areas, giving a total about of 100 million trees. It is estimated that there are nearly 1.6 million trees in the Samarkand region alone.

Yields of younger trees (8 to 20 years) reach only 24% of those of trees over 100 years of age. Even after reaching 50 years of age, trees will produce less than 50% that of an older tree. Yields of trees in May, when the leaves are used for the production of silkworm, were nearly 50% higher than yields in October. Only the harvest of May is used in silkworm production. Thus, assuming the existence of only small trees there will be 1,800 tons of leaves available in October in Nurata project site area. The values of CP and ME vary according to the species. For instance, the black mulberry leaves contain 7 to 18.7% of CP with a DMD 69%. With a high value of metabolizable energy, mulberry leaves definitely can be considered as a natural concentrate to feed ruminants and integrate feeding diets for strategic feeding or for fattening purposes.

Production Orientation/Diversification: Market Opportunities

Market Assessment

All seems to indicate that land-locked Central Asia should look first into its own market demands and capture all existing market niches. In Uzbek Karakul sheep farms, more revenue is generated from meat production as compared to traditional pelt and wool production. Because of large production volume, only Cooperative farms have some profit from pelt production, but still the main profit comes from meat. Meat in these systems accounts for 57% of the profit, while, in comparison, the production of Karakul pelts and wool accounted for 80% of the profits during the Soviet Union era (ICARDA, 2002). These findings clearly show the importance to look at different means to produce lambs at low cost - and faster.

A considerable local demand exists for milk and dairy products. This is particularly true for periurban systems that could access the markets with more advantage if marketing problems are solved. Though the production of sheep milk is not

yet developed, there is a local tradition of consumption, in particular in rural areas of Turkmenistan and Uzbekistan, that could be captured to open an avenue for production diversification and capitalization of added value. Other products in demand in local markets include ewes for reproduction purposes demanded by emerging individual farms, targeting the increase of their flocks and the promising markets for hay and conserved fodder. It is likely that as farmers build their flocks and also their feed-feeding chains, the demand of these products will reverse.

Farmers should be aware of the risks involved from depending exclusively on fiber production or on meat production. Special fibers are subject to quite volatile markets and aggressive competitors. Small holders will benefit from diversified production (including improved reproduction rate for meat in fiber animals) and concentrate on fine wool and special fibers wherever a genuine competitiveness can be verified and other activities or diversification options have been evaluated. Research on markets for fibers is still needed, without disregarding the export opportunities and niches, such as those for fine fibers (Mueller, 2000). Fiber production if meeting quality standards can actually complement the income derived from other products such as meat (Kerven et al., 2002)

During Soviet times, emphasis was on bulk production but, in the foreseeable future, quality will determine market possibilities and price level. Farmers may be instructed to follow a quality production protocol, including simple but relevant rules. In general, these schemes require initial investments in training of farmers and extension officers, but progressively become cheaper and independent. Some aspects may require adaptive research and development (for example about appropriate fiber classification system). Aspects connected with the market of wool have been started by the University of Wisconsin-Madison and the Macaulay Institute (GL-CRSP, 2002)

Flock Management and Feeding Strategies to Target Markets

Current production strategies fail to take full opportunity of production niches, for instance, the management follows that implemented during the Soviet Union when resources were not limited to cover critical periods of the year. Under the new production scenarios, changes in management need to be researched to explore options for coping better with problems and target the available market opportunities. Two examples are considered in this regard.

- 1. Early lambing.** Results of early lambing in the conditions of foothill semi-deserts are confirming the potential of this technology to improve Karakul and Sarajin sheep production in Uzbekistan and Turkmenistan. This technology allows ewes to benefit from spring pastures to restore body weight faster, increase the crop of lambs, produce healthy lambs reducing lamb mortality

rates, produce good quality pelts (in the case of Karakul sheep), and accelerate weaning. The results conducted in collaboration with scientists at the Karakul Research Institute of Uzbekistan showed that the drop in weight from mating to lambing was more accentuated in late than early mating/lambing. The drop in body weight in ewes mated/lambled in August/January, September/February and October/March were 6.6, 9.2 and 9.7 kg, respectively. The weight recovery in ewes that lambled early (in January and February) was faster than those lambing in the traditional period, thus it is expected that fertility rates of early lambled ewes will be improved. In all cases, the earliest lambing animals reached the heavier post lambing weights by June. The striking result was observed in lamb growth. In the Uzbekistan trial, by April-May the lambs born early in January had already reached the weights that lambs from the traditional period would attain at the time of their weaning in July (Fig. 7). This finding opens the possibility of weaning lambs by May and placing them in a fattening program to target market opportunities, or if good summer pastures are available, grazing them for natural fattening in the range (Nagul system). In any case, lambs will be less impaired to pass their first summer in comparison with lambs born in March, which will have to confront the hot summer during a period of intense growth.

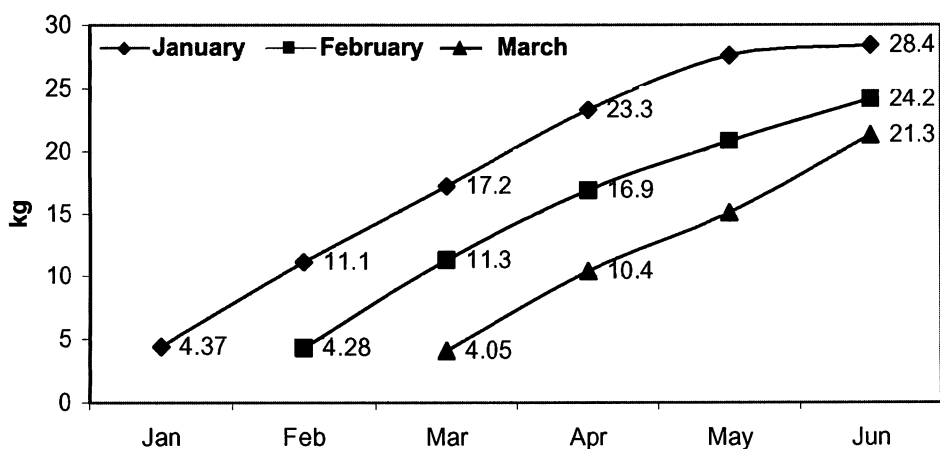


Fig. 7. Growth of Karakul lambs born in three lambing months, February, and March (the traditional lambing month) in Nurata, Uzbekistan.

2. *Generating income and capturing value addition possibilities: lamb fattening.* Different fattening strategies were tested in Uzbekistan, Kazakhstan and Turkmenistan, adding to the menu of alternatives for generating income. Lessons were learned in looking for a way to maximize the profits of farmers at minimum cost. While in some areas, like in Kyrgyzstan and Kazakhstan, having good rangelands and feed grain available the Nagul system, seems to be the base for building any fattening strategy, in the Turkmenistan and Uzbekistan desert steppes the strategies depend less on the Nagul system.

The Nagul system that consists on fattening or pre-fattening lambs in the rangelands, after their weaning, has proven its efficiency in the case of good range fodder availability in summer ranges. The additional achievement was the introduction of feedblock technology, associated with fattening trials and trials involving strategic feeding. This new technology that is now being used in Uzbekistan could be the vehicle to integrate available agro-industrial byproducts for intensive production diets such as for fattening.

Diversification of Production Monoculture

The emphasis of sheep production in Central Asia was on wool and pelts. Meat production was a consequence rather than a main target of the traditional production system, and milk was excluded as a production alternative. The current need for a diversified production moved to investigate the potential of milk production in the context of the Karakul system, in collaboration with the Turkmen Agricultural University of Ashgabat, Turkmenistan and the Karakul Research Institute of Samarkand, Uzbekistan.

In the pelt system still practised in particular in Uzbekistan and Turkmenistan, the slaughtering of the new born lamb for its pelt determines the automatic weaning of ewes at birth (Mary ewes). The milking yield of 50 Karakul Mary gray and black ewes was monitored for a period of 70 days, from March 20 till May 29. This is a characteristic period of suckling, before the start of the summer in Karakul farms in south Kyzylkum. A total of 54.5 kg of milk were obtained in this period. Such a production, though low compared to specialized sheep milk breeds is a potential to be capitalized for added value and women's work.

Considering the local knowledge, pertinent transformation technologies from West Asia were introduced. But farmers move faster. The application of milk transformation techniques learned directly by farmers in a traveling workshop in West Asia, opens new production possibilities for farmers to exploit. Farmer Mr. Kydyrguly Sapargulyev from Turkmenistan milked for the first time 40 of his Sarajin ewes to obtain 1,148 kg of milk at an average rate of 28.7 kg per ewe. With technologies learned in West Asia, he transformed the milk into 230 kg of cheese that was sold for about US\$380.

Assessment of Diversity and the Means to Restore Breeding

ICARDA has undertaken a major research in the cataloging of small ruminants in Central Asia. Information on breed on-station characterization available obtained during the Soviet Union has been condensed and documented by country (Iñiguez, 2004). This information is presently being edited and will be published as a first step towards the management of the breed diversity in the region. Efforts involving the on-station characterization of breeds were also conducted. To this end the monitoring of on-farm production of only major indigenous breeds was started in each country in order to realize the actual production performance of the breeds outside controlled environment and to learn more about the suitability of indigenous vs. improved breeds under current conditions (see example below). ICARDA is looking at collaboration with advanced research organizations to undertake the genetic characterization of the breeds to identify possible relationships among breeds and identify the priorities to set further steps in the conservation and management of these resources.

Another equally important problem relates to the access by farmers to improved animals, indiscriminate crossing that places a risk to the genetic integrity of indigenous breeds, and for the same reason the disappearance of many synthetic breeds, mostly producing coarse wool. Fortunately some indigenous breeds that apparently suit better the market needs are affected less and their numbers are increasing.

During the transition, farmers looked at different options to supply the existing demand and thus generate income. This apparently caused a change in the genetic structure of flocks that is reflected in the rapid increase of local breeds, in particular fat-tailed animals at the expense of a reduction of fine-wool sheep (Fig. 8).

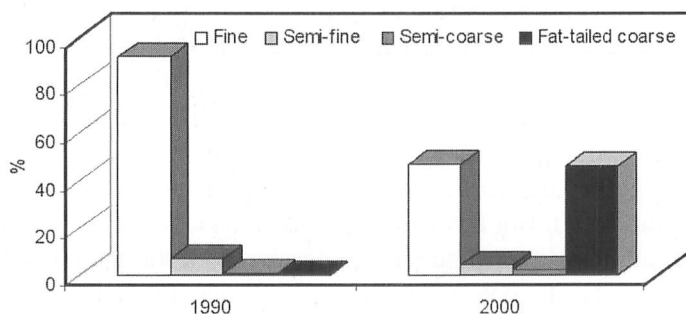


Fig. 8. Distribution of wool-sheep breeds in Kyrgyzstan in 1990 and 2000.

To learn more about the determinants of this trend, flocks including traditional fine-wool breeds developed during the Soviet Union and indigenous fat-tailed coarse wool were monitored in ICARDA's on-farm network in Kazakhstan and Kyrgyzstan in collaboration with the Kazakh Sheep Research Institute, Almaty and the Kyrgyz Livestock Research Institute, respectively.

Weights of Kyrgyz fine-wool and indigenous fat-tailed sheep at the age of one year, 18 months (prior mating) and 23 months (after lambing), in comparative contemporary groups under range feeding, showed no differences (in all cases averaged about 34 kg, 46 kg and 38 kg, at 12, 18 and 23 month, respectively). The drop in weight from mating to lambing (about 7 kg) was similar in both breeds. With similar fertility rates (91%) fine wool sheep showed more prolificacy than fat-tailed sheep (119 vs. 103%, respectively), however survival rates were lower (89 vs. 93%, respectively).

Furthermore, lambs of both breeds grew similarly until the first month, but at the age of eight months, under fattening, fat-tailed lambs were 5.3 kg heavier than Fine-Wool sheep (40.8 vs. 35.5). Differences in wool production per head clearly showed the superiority of the Kyrgyz fine wool sheep over fat-tailed sheep (3.7 to 4.7 kg per head vs. 1.5 to 1.7 kg per head from spring shearings). The better ability of fat-tailed lambs to grow faster in addition to the preference of consumers for this type of meat represent an advantage if wool, prices are depressed, as is the case in Kyrgyzstan.

The studies in Kazakhstan showed the superiority of indigenous sheep raised under winter ranges, over fine-wool sheep, even that price per kg of wool was assumed high. The contribution of 100 ewes of each of three breeds. Indigenous fat-tailed, and fine and semi-fine wool breeds raised under different options reflected this (Fig. 9), under the assumption of a reasonable price of wool per kg (which is not usually the case). The response of fine-wool sheep to stall-feeding and the better response of fat-tailed sheep under range conditions may reflect the better adaptation of the latter. The better survival of fat-tailed lambs, the better weights at marketing times, and particularly the preferential prices for the meat of fat-tailed, as compared to fine wool sheep, seems to explain the rapid increase of indigenous fat-tailed sheep in the country as the most suitable type of animal for the present market environment

The high demand for lamb in the markets, the better outputs obtained by indigenous sheep under low cost winter ranges, and the high preference for the type of meat produced by indigenous sheep suggest to look at the local diversity to determine the best genotypes already existing that suit specific production ecosystems.

INSTITUTIONAL STRENGTHENING

Scientific organizations in Central Asia are poorly equipped, and their staff is underpaid. Though improvements are occurring in some countries, this situation is likely to continue in the near future. Structurally, the national programs follow former Soviet management style and are still non-decentralized. Under this condition, young scientists have little space for development, research visibility, or access to training. ICARDA learned that the less traumatic and most effective option to overcome these problems was a balanced approach for involvement of both senior and junior staff, which also fits within the cultural values of the region. The success of this approach was facilitated by the training in English language of young scientists that should be continued to promote a required level of communication with the world's scientific community.

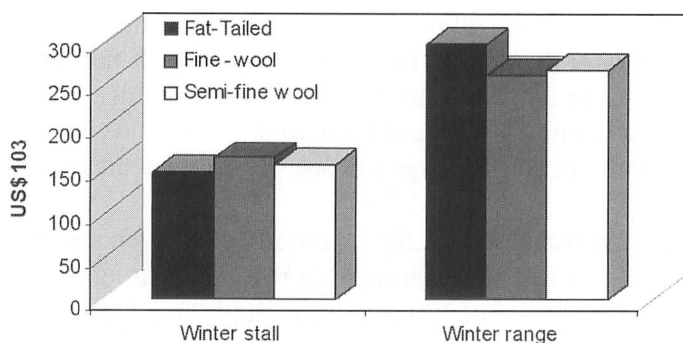


Fig. 9. Revenue of three sets of 100 ewes of fine-wool, semi-fine wool and fat-tailed sheep breeds in Kazakhstan.

If there is an urgent action to facilitate the development of research in Central Asia, this involves training of scientists, particularly in problems-solving and community-based research, upgrading of research infrastructure geared to solve production problems and promote if not restore a desirable level of communication exchange within the region.

The needs in institutional upgrading and improvement are great. In fact, improvements are needed in all areas. While the countries have acceptable skills in biophysical sciences, the area of socioeconomics is the weakest. There are few researchers with experience in this regard because the associated disciplines simply did not exist during the Soviet Union. Filling this vacuum is difficult. Trained scientists are in great demand so that any effort in this direction should

factor in the possibilities to lose the people in the process, though the region still benefits insofar as the scientists remain in it.

Serious steps should be taken to invest in the training of young scientists in advanced research institutions furthering academic degrees for them to return and develop the critical mass for the development of sound research organizations. ICARDA has made significant efforts in improving the skills in the areas of socioeconomics and other production-related disciplines, however a major undertaking is required through the use of bilateral aid and the direct intervention of advanced research organizations.

ICARDA realized that the implementation of regional training workshops on research methodologies were instrumental to rapidly upgrade skills. If these events were conducted with the participation of scientists from advanced research institutions the benefits would be more obvious because of the links established. Topics such as participatory research, community-based research, and impact evaluation should receive attention. Lastly, traveling workshops have proven to be very effective in transfer of knowledge for both farmers and scientists who picked up technologies and tools rapidly; back home, they already have adapted them for local use.

CONCLUSIONS

The effects caused by the transition to a new economic system in Central Asia have significantly affected the livestock production sector. The change was not paralleled by adequate institutional arrangements both in the farming environment as well as in the research environment. Thus, farmers did not find adequate access to new market opportunities, and research failed to address farmers' production problems and constraints that remain unsolved.

The most significant and effective change involved the shift from a stated and cooperative owned tenure to a private tenure; however, this also caused the fragmentation of the land and the immediate emergency of a vulnerable sector of smallholders, mostly landless, having few animals. The opportunity for research resides in that it should be geared to help new farmers in coping with the present constraints.

Though limited, market opportunities exist in the countries and could give place to options for reorientation or diversification of the production systems. However, investments should be made in carefully learning the socioeconomic implications and institutional arrangements needed for effective changes to take place. The different application of reforms in the countries leading to different sets of farm environments and conditions offer a unique opportunity to look upon in order to identify complementarities among farming systems that could be capitalized for better exploitation of the natural resource base and market targeting.

This will require adequate training of scientists, particularly in the areas of socioeconomics and research on the farm environment, in addition to upgrading research facilities to suit problem-solving research. The training of farmers in the use of new methodologies and approaches to compete in open markets should receive priority. In this quest, the collaboration of all international research organizations, such as those under the international research centers (CGIAR), national research programs from other countries, and advanced research institutions will have a determining role.

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Economic Transition Impact on Livestock Production in Central Asia: Survey Results

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ABSTRACT

The dramatic changes in the post-Soviet Central Asia have impacted on the livestock sector and the livelihoods of the rural communities. The most critical of these changes include the restructuring of former collective farms, the formation of new private farms and the changes in land tenure and property rights. The traditional markets have been lost to producers due to the disruptions in the market integration of the former production system and because of economic liberalization. New national trade policies and rules have created new trade barriers. Poor infrastructure and weak linkage to market outlets have constrained the access to the domestic markets. This led to a dramatic reduction of livestock numbers. The reforms are uneven in different countries and private farms are gaining increasing prominence in the countries with more vigorous privatization program. This study documents the constraints on livestock production faced by newly formed private farms and recommends actions at the technological, market and policy levels for improving livestock productivity and the welfare of rural communities.

INTRODUCTION

The five Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) have a total population of 56 million people and a landmass of 400 million hectares, out of which around 70% is arable land. There are important socioeconomic differences in these five countries. The most populated country, Uzbekistan, which has about 44% of the region's population has only 10% of the arable land, while Kazakhstan, which is the largest country, has the largest share (73%) of the arable land, and has about a third of the population. However, Kazakhstan, which is the most developed and industrious country, is the

least dependent on agriculture, contributes to about 10% of the Gross Domestic Product (GDP), whereas this sector accounts for 44% of the GDP in Kyrgyzstan, and 34% in Uzbekistan. Agriculture is the main source of export earnings (31%) for Uzbekistan, making it a vital sector for the livelihoods of the large rural population.

Dramatic changes have taken place in the agricultural sector of these countries since the disintegration of the Soviet Union. These changes include the complete or partial *dismantling of the large agro-food complexes*, the *privatization of large-scale cooperative farms*, and *general economic reforms*. The consequences of these changes were a complete disruption and disintegration of the established marketing systems, loss of traditional markets, such as Russia, a decline in rural public services, a decline in agricultural investment, a complete transformation of the production systems from cooperative farms to mixture of different farms, and the emergence of individual private farms. *One of the outcomes of these changes and their effects were a sharp decline in livestock numbers in some of the countries.*

However, legal and institutional reforms did not keep pace with the changes in the production systems and in the wider economic environment. For example, a proper legal framework that establishes land property rights and that can stimulate private land ownership and the development of land markets did not proceed fast enough. These institutional lags had significant impact on the poor and the less powerful. Similarly, changes in the production systems from Collective to private ones were not supported by the necessary infrastructure in financial, extension and other farm services such as veterinary services that are essential for the development of a private-led market-oriented sector. These services have instead declined. The lack of financial services has limited the growth of emerging private farms. These farms face shortage of critical capital, which limited investment in farm machinery and the purchases of essential farm inputs. As a result, these farms operate old and inefficient farm machinery. Lack of information and extension services also became a constraint to producers in developing farm management skills and access to market information. These factors led to a *decline in the livelihoods of the rural population in these countries and the rise of rural poverty.*

Kazakhstan, followed by Kyrgyzstan, recorded the highest degree of privatization, while Uzbekistan followed by Turkmenistan, reformed gradually. These reforms were compounded with several problems that determined the loss of about 80% of the national flock in Kazakhstan and 70% in Kyrgyz Republic. With less reforms applied, the national flocks of Uzbekistan and Turkmenistan changed little in 10 years post-Soviet Union

As part of a forage and livestock improvement project, a socio-economic characterizations and diagnosis of the production constraints of livestock systems

in the CA countries were carried out. The main results of this diagnostic study are presented here. Objectives of the study were to characterize and diagnosis problems of emerging small ruminant production systems, and develop constraint analysis of markets and analysis of market potentials to reorient production systems, and identify solutions to market problems.

METHODOLOGY

The research was conducted in areas selected for the implementation of an "Adaptive Feed and Livestock" research project. These areas were selected on the basis of their importance in livestock production and representation of prevailing livestock production systems. A brief description of the study areas are given below.

Central Asian Republics' Study Sites

Kazakhstan

The study area in Kazakhstan is located in Jambul District (Rayon), in Zailiy Alatau foothills, 50 km north-west of Almaty city. The areas has open springs and wells used for irrigation. There were about 970 individual and peasant farms, seven production cooperatives, five joint-stock companies, two partnerships with limited liability, two national experimental farms exist in Jambul District (Rayon). There is a mixed livestock and meat production in Jambul District. The main agricultural produce is grains and vegetables (mainly potato), commercial crops (sugar beet and tobacco), and meat and milk. Currently, there are about 18 mills, ten private small medium scale bakeries, two pasta-producing plants, three meat processing companies and two butchering houses. The main market outlets for the region are in Uzun-Agash district center and the city of Almaty.

Kyrgyz Republic

In Kyrgyz Republic, the study covered private family and peasant farms located in the mountainous area of Kemin and Kochkor districts, with mixed crop-livestock systems. Kemin is closer to Bishkek city and operates as a peri-urban production system with strong interaction with cropped land. Kochkor is more rural and situated in the highlands.

Uzbekistan

In Uzbekistan, two areas with distinct production systems were selected: Parkent and Nurata. Parkent district is a peri-urban area located in a 45 km from Tashkent. Because of its diversified natural resources consisting of rangelands,

rainfed hay lands and irrigated areas, Parkent has a mixed crop-livestock production system. Small river streams and dug-wells provide water for domestic use and irrigation purposes. Cooperatives play an important role in the district's economy in terms providing employment for local people and supporting local schools and hospitals. Dairy cattle are supported by cultivated fodder, while sheep are managed on extensive rangelands with supplementary feeding in winter. The market outlet is the city of Tashkent.

Nurata is located in the Navoy Province, a traditional territory of Karakul sheep production with annual rainfall of about 250 mm. A large portion of the area (75%) extends over a steppe land having shrubs and grass vegetation. The district has nearly 350,000 heads of Karakul sheep (black, gray and sur), 4,000 cattle, 1,500 horses and about 1,000 camels. Most of Karakul sheep are raised in cooperatives. The main market outlets are in Samarkand and Tashkent. Production systems in both districts are dominantly represented by households and less by peasant farms and cooperatives.

Turkmenistan

In Turkmenistan, the study was conducted in Yerbent, Baharden, Geokdepa and Rukhabad districts of Ashgabat region. Surveyed farms are located at the borderline between the valley at the foothills and the Central Karakoum desert, with annual rainfall of 150 to 170 mm. All farms have access to irrigation and drainage channels. In Yerbent district, more extensive livestock production systems is dominant, where flocks migrate towards Central Karakoum desert in summer. Geyokdepe, Baharden and Ruhabad districts practice more intensive agriculture relying on cultivated fodder such as alfalfa. Livestock in these districts are managed around the farm throughout the year, supplemented with feed produced on the farm and with a short period of summer grazing in nearby mountains. The outlet for crop marketing is Ashgabat.

Sampling

Initially rapid rural appraisals were conducted to identify farm types and main production systems and market channels. Then a sample of different types of producers, traders, retailers and consumers were surveyed. The producers survey covered household plot farms, some of whom were members of the cooperatives and some non-members, private family and peasant farms, and cooperative farm managers. The consumer survey covered urban and rural areas.

A total of 700 producers were interviewed which and divided into three types of households. These were agricultural cooperatives (13), small holder household farms (250), some of which were members of the cooperatives and other which

are not members of cooperatives, and individual private family and peasant farms (410) which are small union of 2-7 farmers who pool their resources and work together. The sample structure is given in Table 1.

Table 1. Structure and numbers of surveyed farms, middlemen and consumers in Central Asian countries.

Targets	Kazakhstan	Kyrgyzstan	Turkmenistan	Uzbekistan
Producers				
Households	50	150	200	200
Private farms	45			15
Cooperatives	7			6
Total	102	150	200	221
Middlemen				
Rural market	30	50	91	25
Urban market	170	150	9	75
Total	300	200	100	100
Consumers				
Rural market	30	100	60	100
Urban market	170	200	40	300
Total	200	300	100	400

In Kazakhstan, the survey covered 50 households, 45 private family and peasant farms and 100 workers of 7 AC. In Kyrgyz Republic, the survey covered 150 private family and peasant farms, 200 middlemen, and 300 consumers. In Turkmenistan, two livestock farm types, individual farms (IF) and private producers (PP), were surveyed. A total of 137 individual farms and 63 private producers were interviewed. In Uzbekistan, the survey was conducted in Parkent and in Nurata district. The surveys were completed in October-November 2001.

The producers survey focused on the nature and constraints of livestock production systems, including access to natural resources, production costs, capital, sources of income, and production constraints. The farm characteristics information gathered included farm management, family size and gender, land tenure and property rights, natural resources utilization, access to markets and opportunities for production diversification.

FARM CHARACTERISTICS

Farm Typologies

The agricultural reforms during the economic transition in the Central Asian countries have led to the formation of different farm types. The restructuring of the former collective farms (sovhoz and kolhoz) has led to the formation of a variety of farm types with different ownership forms and organizations. These countries are at different stages in the economic and institutional reform, which led to the co-existence of the different farm types. These include: (i) *household plots*, (ii) *family farms*, (iii) *peasant farms*, and (iv) *agricultural cooperatives* (such as joint stock companies, limited liability companies and cooperatives). All of them acquired their agricultural land as a share of former Collective farms. These farm types are described in Table 2.

The Household Plots

These are highly associated with the Cooperative farms. These are small-scale private farm enterprises, consisting mainly of vegetable gardens and livestock. Most of these households are associated with joint stock companies and cooperatives where they work or may be completely independent of them. In the former case, these households only receive wages and the later they receive their share of the profits (at least in principle) and may also work and receive wages. Many of these households are still dependant on the cooperative farms for employment, input supply (fuel, lubricants and machinery), provision of veterinary services, product marketing, community services such support for rural schools, kindergartens for children, hospitals and food stores.

The Family Farms

These consist of a single family who manage own crop and livestock production. In most cases they have a long-term lease of land, for example, 99 years in Kazakhstan based on what is known as the "Gos Act". The single-family production units may be associated with a nearby cooperative in many ways. They may work there, rent out their land or collect hay from their pasture land. In Turkmenistan, another form of family farms are the predominantly private livestock producers with larger holdings than crop-based households and do not own agricultural land. These types are common among sheep and camel producers in Yerbent district.

The Peasant Farms

These are small groups of related families who pool their resources and work together in partnership. They can legally operate as one operation managed by a

family member. They form an important group in livestock production and are increasingly gaining importance. In many cases they are totally independent of the former State farms, while in other cases, they significantly interact with agricultural cooperatives (Joint stock companies and production cooperatives). For instance, they may lease or rent out their crop land to the cooperative; they may also depend on the cooperative for feed supply and marketing animal products while the cooperative may depend on these farms for labor and raw material supply to their processing industry.

Both of the above two farm types (family farms and peasant farms) are private, but they only differ in the number of owners. The family farms are owned by single families, while the peasant farms are formed by a few (2-7) closely related families and are managed as one unit. The two farm types are similar in all practical purposes and in the subsequent discussions they will be called as private family and peasant farms.

Agricultural Cooperatives

Include the joint stock companies, limited liability companies and the production cooperatives (*shirkats* and *dekhans*). They have large number of members and large-scale operations. Although many of these are reborn as private cooperatives, they are still managed, in many cases, as former collective farms. The joint stock companies and limited liability companies are common in Kazakhstan with up to 200 members and large farm operations. They have legal basis for longterm land ownership from 1949-'99 years.

The production cooperatives that exist in Turkmenistan (*dekhans*) and Uzbekistan (*shirkats*), where economic reform process is slower, are in principle supposed to function as modern cooperatives. However, they largely remain as former collective farms. They occupy large areas of arable land and play an important role in the functioning of both individual farms and households. Some have vertical integration of production, processing and marketing systems. Managers are still appointed by government authorities rather than by cooperative members. Revenues are distributed equally rather than on actual efforts. The property rights of the different forms of cooperatives are quite complex and are in a state of transition.

The description of one cooperative in Uzbekistan shows this complexity and challenges facing the policy and intuitional reform of former Collective farms. In some cases, there are contractual arrangement between cooperative farms and households. The cooperatives, in addition to providing employment to household farmers, act as government channels for delivering subsidized foodstuff (flour, rice, sugar, and winter clothes) to households. However, as the reform process continues and markets develop these may not remain as production units in the future.

Table 2. Characteristics of farm types in the survey from Central Asia.

Farm type	Ownership type	Number of owners	Land area
Kazakhstan			
Household plots	Private land ownership with the right of inheritance	Single families	Small plots below 1 ha
Peasant farms (individual farms)	Private land ownership on a long-term rent base from 5 to 49 years.	2-3 families, or the largest up to 7 families	Small from 7 ha and large up to 250 ha.
Agricultural Cooperatives	Private land ownership on a long term rent base from 49 to 99 years. This includes limited liability and joint-stock companies	Large number up to 200 members	2,000-14,000 ha of total land
Kyrgyz Republic			
Family farms (Small-Scale individual farms)	Private land ownership	Single family farms Mainly livestock production	Minimum 1 ha irrigated land in mountainous, and 5 ha in non-mountainous areas.
Peasant farms: Medium scale individual farms	Private land ownership	Several families Importance of crops increase	Land area varying from 5 to 150 ha
Agricultural Cooperatives	Private land ownership	Several households or family farms that are cooperative members.	Land area varying from 5,000-87,000 ha
Turkmenistan			
Household plots	Private land ownership	One family	Small plots of about 1/4 ha and around 15 heads of sheep
Family farms	Private land ownership	One family	Variable ranging from 3 ha to 150 ha
Private (peasant) livestock producers	Mainly sheep and camel producers	2-3 families	No arable land, no land property rights, rely on sandy in Kuzikum used as common rangelands.
Agricultural cooperatives	Practically similar to old collective farms	Consists of cooperative members	Large farming units operating on vertical integration
Uzbekistan			
Households: -Shepherds	Private ownership with share of cooperative assets	One family	0.25-1 ha
-Non- shepherds Individual (peasant) farms	Private ownership. They can run their farming business individually or if they are members of the cooperative by taking their share and running their own farming	1-5 families	Variable ranging from 5 ha to 200 ha
Agricultural cooperatives (Shirkats)	Practically similar to old collective farms, but on paper the households are members of the Shirkat that produce under contractual agreements	Large households (up to 150 members)	Occupy large areas of land up to 14,000 ha in Parkent and over 100,000, mainly rangelands, in Nurata.

Box 1. Reforming Former Collective Farms: Boykozon (Uzbekistan)

Boykozon Farm is a former Soviet-style Collective farm, which has been transformed into a production cooperative or Skirkat. The farm has 8,000 ha, of which 3,000 ha are irrigated and 5,000 ha are rainfed. In principle, members of the cooperative who are the same households under the collective system own the farm. In reality, the new cooperative has the same management as before. The 1500 households in the farm are working within the cooperative through land leases. Individual households are given a lease of 15 years for about 5-10 ha for grain crops, potatoes, and 1-2 ha for fruit trees. This lease program is an attempt to devolve some farm management decisions to producers and provide incentives for hard work and higher productivity, and hence increase the overall farm efficiency.

In addition to the lease, farmers have written contracts, copies of which are available at the cooperative management office, which indicates land use plan, estimated cost of production, quota of production to be marketed through the cooperative, and allocation of proceeds from farm sales. The contract includes the allocation of the estimated revenue from sales in to cost of production, including wages paid to farmers and their families, cost of inputs such as fertilizer and fuel, machinery services, depreciation of pooled capital equipment, technical services by agricultural specialists, and others. The cooperative provides all inputs other than labour, machinery services and technical expertise.

The procedures for calculating these costs and particularly wages are not clear. What is clear is that the individual producer has less control over the income side of the production. It is reported that the net returns or profits of the farm are divided as follows: 30 % (less the wages already calculated in the cost of production) is paid to producers, 35% goes to the development of the farm, 28% is paid as dividends and 7 % is contributed to a social fund.

There are certainly efficiency and equity implications of alternative mechanisms of sharing responsibilities and roles between the Management Unit and producers in management and control in the production-marketing chain and in provision of services. Apparently policy makers has faced this concern and used the land lease and contractual arrangements as a step towards devolving some control of the production process to producers. This certainly improves production efficiency, but it is an intermediate remedy and does not sufficiently respond to the efficiency and equity concerns.

The challenge here is how to ensure that former Collective farms are transformed into equitable, and sustainable profitable market-oriented farms without facing the painful experience in the other Central Asian countries where the transformation came abruptly and as a result agricultural production fell sharply and many people lost their livelihoods. The challenge to the research community is to provide analysis of the costs and benefits of different courses of action.

Source: This assessment is based on an interview with the Collective's management.

Although the agrarian reform is still in its early stages of development, and many institutional reforms are yet to be completed, its impact on land tenure and farm structure has been significant. The large-scale farms no longer dominate agricultural production. The small- and medium-scale private farms (peasant farms, family farms and household plots) now form the most important sector in livestock production in countries with the more advanced stage of economic reforms such as Kazakhstan and Kyrgyz Republic. These farm types now hold

over 80% of the livestock, and supply the bulk of livestock outputs. For example, 90% of meat and dairy products are produced by small scale household farms in Kyrgyz Republic. In Uzbekistan, although average stock of animals per household is low, these farm types hold 86% of cattle and 67% of the whole population of sheep and goats.

These farm types have also more clearer land tenure systems and ownership structure. In Kyrgyz Republic the family and peasant farms are the dominant farm types producing nearly 65% of national agricultural output. Medium-scale private farms are developing gradually. However, their role in total livestock production is still small, as it varies from 1% (Uzbekistan, Turkmenistan) to 5-10% (Kazakhstan, Kyrgyz Republic). Nonetheless, development of suitable institutional frameworks that support the new organizational and ownership forms for complete shift from former Collective and State farms to private farms in an effective and equitable manner still remains a challenge to policy makers.

FARM RESOURCE ENDOWMENTS

The farm resource endowments for different farm types vary widely. As indicated earlier, the household plots have very limited agricultural resource base, only vegetable garden, about a dozen sheep and few cows. These households were, in the past, the labor force of the Collective farms which, in turn, provided them secured livelihoods and essential social services. Although many of them still rely on the agricultural cooperatives for employment, they have largely lost the livelihood security they enjoyed in the past, making them the most vulnerable group in the rural areas.

The livestock-based households in Turkmenistan do not own land but have larger sheep flocks, nearly 200 heads per household on average. This lack of feed resource-base makes them rely more on feed markets during critical periods. In Uzbekistan, livestock-based households have, on average, close to 300 heads of sheep and along with them manage another 750 heads for the Cooperative (Table 2). They own less than half a hectare of land. While the crop-based households have 24 heads of sheep and slightly less than a hectare cropland, they are relatively less experienced in livestock production; only 14% of them said they had experience in livestock production. These households raise livestock as additional source of income, however, they have virtually no grazing and hay land. The landless households in the survey were 13% in Kazakhstan, 12% of the shepherds in Nurata (Uzbekistan), and all the livestock producers in Yerbent (Turkmenistan) (Table 3).

But more critically, many of these poor-households have feed resource-base (hay and range lands). For instance, all households plot farms surveyed in Kazakhstan, and 62-86% in Uzbekistan have no rangelands. Only the shepherd

households in Nurata have rangelands. Similarly, these households farms (97% in Kazakhstan, 43-92% in different locations in Uzbekistan) have no hay land. This lack of feed resource-base severely limits the options for these households to reduce feed cost and increase farm income.

The family farms and peasant farms have larger agricultural resources (Table 4). However, their resource endowments significantly vary with in the sample in each country and between countries. The family farms in Kazakhstan have the largest land resources among these farm types, about 10 ha of irrigated land, 40 ha of rainfed land for crop and hay production, and nearly 50 ha of rangeland. However, they have relatively lower animal resources. This can be explained by the fact that livestock assets were easy to be liquidated for acquiring farm equipment and inputs during the transition period, when barter exchange became common in the rural areas due to cash shortages. This low livestock assets relative to the feed resource-base, however, indicate that these farms have a potential to build up their livestock resources. The proportion of goats in all farm types in Kazakhstan was high: 20% in cooperatives, 29% in family and peasant farms, and 48% in household plot farms.

The peasant farms in Kyrgyz Republic have fewer resources than those in Kazakhstan. They hold on average about 3-4 ha of irrigated land and have virtually no grazing or hay production land. However, these farm types have about 50 sheep, 4-10 cattle and 3-5 horses. Similarly, the family farms in Turkmenistan have about 8 ha of irrigated land on average, but have no grazing land or hay production land. They have much smaller sheep flocks but relatively more large-ruminants herds (cattle, horses and camels). Most of them rely on rented land. Out of 137 surveyed farms, 80% used rented land, and 20% were landowners. They all rely on common rangelands. The peasant farmers in Uzbekistan have on average 8 ha of crop land, mostly irrigated; about 60 heads of sheep and virtually have no rangelands. In Nurata district; average size of sheep flock is larger than in Parkent. Cattle is important in the Parkent region, near Tashkent city where these farm types have the largest cattle holdings among surveyed peasant and family farms; about 15 heads per household.

The distribution of landholdings is quite variable in the sampled family and peasant farms. The farms in Kyrgyz Republic seem to be the worse off where the majority (53%) have up to 3 ha. This category is only 11% in Turkmenistan and 6% in Uzbekistan. In Turkmenistan, the 3 to 5 ha landholding class of farms is important accounting for a third of the sample both in Turkmenistan (33%) and in Kyrgyz Republic (32%). The 5-10 ha holding sizes are the most frequent in Uzbekistan (46%) and are equally important (20%) in Kazakhstan and Turkmenistan. Only Uzbekistan and Kazakhstan have farms with landholdings over 25 ha. It worth noting that in Uzbekistan almost all (99%) shepard house-

holds who depend on regular water supply from cooperatives mentioned that water shortage as critical for animal production, while only 58% of other household plot farms who receive water from central systems mentioned similar constraints.

The land distribution analysis reveals that a significant portion of the farms have limited crop land, have no hay land, and have no grazing areas. The most striking resource distribution in the sample is that rangelands and hay lands were almost exclusively owned by large farmers. The family farms and peasant farms that do not own rangelands were 62% in Kazakhstan, 36% in Kemin, and 91% in Kochkor, Kyrgyz Republic, and 32% in Parkent and 45% in Nurata, Uzbekistan. Almost similar portions of the farmers have no hay land. These limitations on feed resources affects livestock productivity and the livelihoods of these resource-poor rural households.

Agricultural cooperatives have significantly large resources (Table 2). The crop-based cooperatives in Kazakhstan and Uzbekistan have land areas ranging from 15,000 to 40,000 ha, with about 13% to 34% irrigated cropland. The livestock-based cooperatives in the Nurata region of Uzbekistan, have relatively limited cropland below 2000 ha mostly (90%) hay land, and vast rangelands over 100,000 ha. All agricultural cooperatives also have large livestock assets, about 5000-30,000 small ruminants. Nonetheless, the more crop-based cooperatives, with large irrigated crops, have more large ruminants herds, mainly cattle, while those in drier areas have more small ruminant flocks.

Table 3. Land and livestock holdings of Cooperative farms in Kazakhstan and Uzbekistan.

Land area and livestock numbers	<u>Kazakhstan</u>		<u>Uzbekistan</u>			
	Mean	SD	<u>Parkent</u>		<u>Nurata</u>	
			Mean	SD	Mean	SD
Total arable land area (ha)	0.2	0.1	0.4	0.3	0.8	0.3
Irrigated	0.2	0.1	0.4	0.3	0.8	0.3
Hay land	-	-	-	-	-	-
Rangeland	-	-	-	-	-	-
Sheep	12	8.7	9	6	24	11.3
Cattle	4	1.9	6	4	2	1
Horse	-	-	2	1	-	-

SD = Standard Deviation.

Table 4. Land and livestock holdings of family and peasant farms in selected Central Asian countries.

Country	Farm type	Location		Irrigated	Hayland	Rangeland	Total	Sheep	Cattle	Horses	Camel
				-----ha-----				-----No.-----			
Turkmenistan	Farmer	Yerbent	Mean	2.9	0.0	0.0	2.9	3	6		11
			SD	0.5	0.0	0.0	0.5	0.5	1.1		.
		Ruhabad	Mean	7.6	0.0	0.0	7.6	8	15	21	26
			SD	4.2			4.2	4.2	8.7	3.3	1.9
	Private producer	Yerbent	Mean	0.0	0.0	0.0	0.0	194	4	1	3
			SD	0.0			0.0	73.4	1.6	0.55	1.8
Kazakhstan	Peasants	Jambul	Mean	9.7	16.2	27.6	29.4	23	5		0
			SD.	0.6	13.4	20.5	24.0	23.7	3.8		0.0
Kyrgyz Republic	Farmer	Kemin	Mean	3.7	3.8	0.0	5.9	56	9	3	0
			SD.	2.4	2.4	0.0	1.6	28.2	4.1	1.8	0
		Kochkor	Mean	2.3	0.2		2.5	43	4	3	0
			SD.	0.7	0.1		0.6	18.4	2.4	1.8	0
	Peasants	Kemin	Mean	3.3	4.5	0.0	6.8	53	10	4	0
			SD	2.7	1.4	0.0	1.2	30	11.2	1.7	0
		Kochkor	Mean	2.9	0.0	0.0	2.9	52	6	5	0
			SD	1.4			1.4	23.8	2.3	2.8	0
Uzbekistan	Farmer	Parkent	Mean	6.7	0.2	0.8	7.7	17	16		1
			SD	0.7	0.02	0.08	0.9	5.7	5.3		0.3
	Farmer	Nurata	Mean	6.0	0	16	22	288	16		4
			SD	0.5		1.7	2.4	92	5.3		1.3

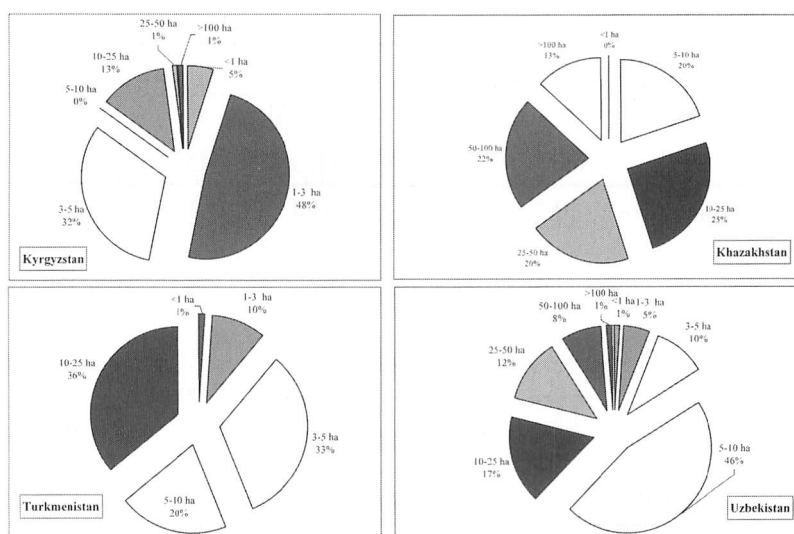


Fig. 1. Distribution of land ownership in Central Asia.

GRAZING ARRANGEMENTS

The countries have different rangeland endowments and the grazing pressure differs depending on the changes in livestock numbers and management systems. In many cases, the different rangeland resources are not equally utilized. The rangelands within the cropped areas, around settlements and around water points are degraded due to excessive use, while remote rangelands are underutilized due to the sharp drop of livestock population, particularly where a drastic decline in animal numbers has occurred, as in Kazakhstan. Farmers and local people in that country pointed out that summer mountainous ranges are not used at all and that newly emerging small-scale farms do not have the resources and capacity needed to organize themselves in order to graze remote ranges. In Kyrgyz Republic, only 23% of the surveyed peasant and family farms reported the use of remote ranges, which leads to overgrazing and declining of vegetation cover in the ranges near the settlements.

In Uzbekistan, where human population density is the highest, surveyed farmers pointed out lack of access and virtual reduction of grazing areas. Farmers in Nurata district have access to large areas of range that are used throughout the year, while in Parkent ranges are confined to foothill and mountainous areas. In the surveyed *shirkats* of Nurata, the stocking rates was 0.29 head/ha and in Parkent 2.5 head/ha. The stocking rates of peasant and family farms was 18 heads per ha, while that of household plot farms was 80 head per ha. The households and most peasant and family farms have virtually no rangelands and other feed resources, while the large private farms and cooperatives, in Turkmenistan and Uzbekistan, hold most of the rangelands. In Kochkor district in Kyrgyz Republic only 9% of peasant farmers have rangelands and in Kazakhstan about 38% of peasant farmers have rangelands. Similarly, in Uzbekistan, 45% and 32% of peasant farms in Nurata and Parkent, respectively, have no rangelands.

As households increase their flock size, they increase their access and use of common rangelands. This creates pressure on grazing areas around settlements and pushes the cooperative (*shirkat*) flocks to increase their use of remote ranges. Farmers reported degradation of ranges around villages due to increased number of users. This occurs because many of the rangelands are common and all farm types use them intensively. As a result, a conflict is occurring between households and private (peasant and family) farms over rangeland use. However, peasant farms and family farms are progressively increasing their access to remote rangelands through consolidated and cooperative flocks. This increased use of remote ranges as common resource is already having its impact and farmers reported indications of progressive degradation.

These use of remote ranges, in principle, can reduce the cost of feed, avoid land degradation in areas around settlements, leading to more sustainable resource

management, and increase the efficient use of available grazing resources. These remote rangelands require either large flocks that can absorb the cost of moving and shepherding or community organization for collective action for joint-herding. The access to remote rangelands can be addressed by institutional innovations such as joint-herding. Collective grazing arrangements of the remote ranges are now being practiced in several communities through joint-herding of mobile flocks. The research project assisted 10 farmers in Kazakhstan to initiate the organization of mobile flocks for collective grazing of remote pastures. The results of this experience, in addition to other indigenous experiences in joint-herding, will contribute to the development of sustainable rangeland management in the region.

Family and peasant farmers in Kyrgyz Republic combine their flocks for joint grazing in public rangelands. The individual farmers in Turkmenistan do not use remote ranges frequently because (1) the herd is not large enough (to be viable for distant grazing, 300 heads are required), (2) the problem of water availability, and (3) high cost of grazing per head depending on the distances from the settlement: 5,000 Manat per head for 50 km; 8,000 Manat per head for 100 km; and 10,000 Manat/head for over 100 km ranges, and (4) lack of cooperation in organizing remote grazing. The utilization of remote rangelands by different farm types is shown in Figure 2.

The landless livestock-producers naturally use remote ranges more frequently than the individual crop-livestock farmers, but about 40% of them do not access. In Uzbekistan, shepherd households manage their own animals and those of the cooperative together, throughout the year, on remote ranges. The distances that flocks move per day depend on the condition of ranges and season of the year. Households farms (non-shepherd) join their livestock in consolidated flocks managed by a hired shepherd for 9 months (spring-summer-autumn) grazing in remote ranges. Similarly, in Uzbekistan, all the surveyed family farms in Nurata district graze their livestock throughout the year on remote ranges. Crop-based household farms join their small flocks in a consolidated flock, which is taken to graze remote ranges for 8-9 months per year.

The households farms in Kazakhstan and the peasant farms in Turkmenistan are dependent on the grazing resources around settlements and do not utilize remote rangelands. On the other extreme the shepherd households who move the cooperative livestock and their own in Uzbekistan, and the landless herders in Turkmenistan are the most frequent users of remote common rangelands. Agricultural cooperatives are also heavy users of remote rangelands, while the private family and peasant farms are less frequent users.

Although, increased utilization of remote rangelands may appear to have reduced the degradation and conflicts over the closer rangelands around settlements it will not solve the core problem of open access use. The problem is that as the number of users increase the pressure on these rangelands will increase. This will eventually lead to land degradation, shortage of feed resources and users conflict. There are already reports that in one case users were evicted from one site by others who claimed property rights over the site.

Another, factor that influences the use of rangelands is *government policy*. In some countries, like Kazakhstan, users do not pay any charges in accessing these remote rangelands. The fact that there is no charge for using these rangelands also raises questions about the sustainability of this management regime in the long term. Degradation of open access remote rangelands is already observed in Uzbekistan due to increased access as other sources decline. In Kyrgyz Republic, users pay a fee per head per month for utilizing these rangelands. In Turkmenistan, farmers do not pay for the use of the range directly but they are obliged to pay the cost of maintaining the wells in the rangeland territory that they use. This payment for well maintenance has virtually become the rent for using rangeland. All farmers who graze their livestock on the rangeland, where wells are located, pay the well-maintenance costs. Farmers agree among themselves that repair payment will be determined on the basis of each farmer's proportion of the flock.

Another important aspect of rangelands use is the issue of *equity in access*. In general, small-and medium scale farms have no grazing land resources while large cooperatives and private farms have large grazing areas. In Kazakhstan, for example, the household plot farms were the least able to utilize these remote ranges, mainly relying on the areas around the settlements, which face the highest degradation. Only a third of the individual farms grazed remote ranges through consolidated flocks and only few (2%) through private flocks, whereas over half of the agricultural cooperatives used the remote ranges, and about 45% relied on the areas close to settlements. But given their relatively large rangeland resources, the grazing pressure is not as great as it is in the common areas around the settlements.

In Kyrgyz Republic, rangelands are State property that can be used on a long-term lease basis (up to 50 years and longer). They are mainly allocated among large-scale farms (cooperatives or individual private farms). Family and peasant farms have limited rangelands. This inequitable land distribution is resulting the degradation of more easily accessible rangelands near the settlements and leading to conflicts between small farms and cooperatives.

Finally, the rangelands of Central Asia face a number of challenges. These include sustainable management, equity in access, and efficient use of all available resources. Further research is needed on the institutional arrangements, and

environmental as well as productivity indicators, to help communities and policy-makers to devise sustainable management of rangelands.

DIVERSIFICATION, COST AND INCOME STRUCTURE

Farm Enterprise Diversification

As the agricultural sector involves, and production systems develop, in Central Asian countries following macro-level policy and institutional changes, opportunities immerge for farm enterprise diversification that increase household income and reduce production risks. Farm enterprise diversification is however affected by a number of factors, including *government policy*, *natural resource base* (holding size, access to water, etc), *market opportunities*, and *farmer experience and entrepreneurship*. These factors vary in different countries and hence their effects are reflected in farmers' efforts to diversify their production.

The household farms, with their very limited land resources, mainly grow vegetables and different fruit trees on their plots. Peasant and family farms in Kyrgyz Republic cultivate grains (mainly wheat), sugar beet, potatoes and vegetables. Those in Kazakhstan grow grains, fodder crops as alfalfa and corn for silage, sugar beet, tobacco and vegetables. Fodder production is one of the profitable crops for in the study area. In Jambul District, farmers are growing tobacco as it has secured marketing from Phillip Morris Kazakhstan Company. Peasant and family farms in Turkmenistan grow fodder crops such as alfalfa, which makes about 42% of the total cropland, grains (wheat and barley) on about 30% of land, vegetables and melons occupy 12% and other crops about 17%. Farmers in Turkmenistan grow barley, alfalfa, fodder melon, maize and pumpkin as animal feed. Farmers participating in the research Project grew non-conventional source of fodder such as halophytes (*Climacoptera lanata*, *Suaeda altissima*, *Atriplex heterosperma*, *Atriplex ornate*, *Atriplex dimorphostegia*, *Atriplex canescens*) after a familiarization workshop organized by the Project. Farmers in Uzbekistan grow legume crops such as peas, mung bean and chickpea due to market demand.

In Uzbekistan and Turkmenistan, mandatory crop area allotment, especially for cotton and wheat, considered as strategic crops, is in effect. Farmers prefer to allocate the largest area to alfalfa, a highly-value commodity in demand, which is sold at open market, while strategic crops are sold through government procurement agencies at relatively lower returns. In Turkmenistan, the flexibility for private farms to grow more area under forage crops is highly uncertain and are not necessarily free from administrative pressure. The district administrators may request even from legally private farmers to change the cropping structure based on district obligations to produce certain amount of strategic crops such as cotton and wheat. This can be regulated by the provision of inputs such as such as water distribution.

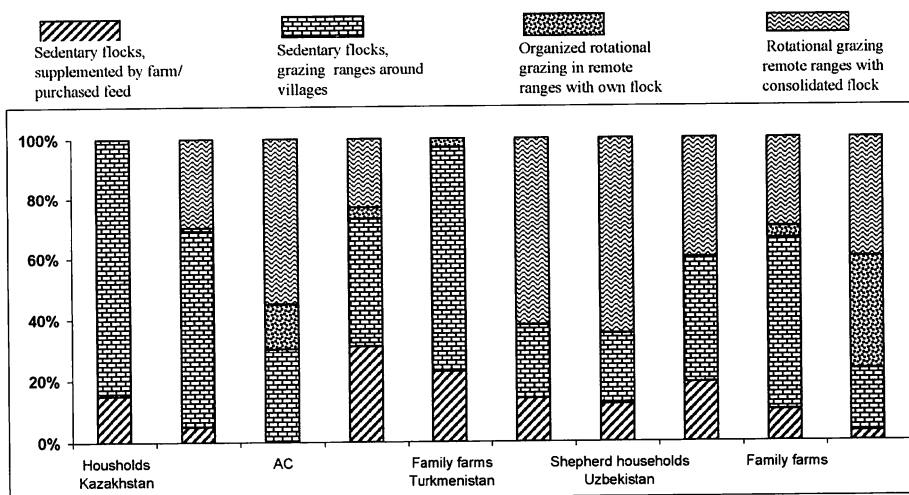


Fig. 2. The access of remote rangelands by farm types in Central Asian countries.

Farm Cost Structure

The cost structure depends on the crop and livestock diversification, and on the degree of intensification, for example use of irrigation. Overall, feed cost accounts for the highest share of the farm costs for the livestock-based farms with little grazing resources and cropland. This is expected given the long winter season of Central Asia. On the other hand, fuel, machinery and wage-labor formed the main costs in crop-based systems with more intensive crop production.

Major cost components of household farm types, in order of importance, are fodder, wages and machinery. These farms have limited crop land to produce feed in winter. The major cost of individual private farms and peasant farms in Uzbekistan was also animal feed, which accounted for about 40-60% of total farm operational costs. However, in the other three countries where production is more diversified and irrigation is used and fodder is produced on the farm, fuel, machinery and wage labor account for most of the farm cost in that order.

Some of these farms that which cultivate crops more intensively have higher fuel costs (involving land preparation, cultivation, field irrigation, and sowing) than household plot farms and other peasant and family farms. For example, in Kyrgyz Republic, private farms have higher fuel costs as they irrigate sugar beet and potato compared to the other farms which are mainly dedicated to livestock production.

Similarly, in Turkmenistan farms in this category had reported fuel and machinery as the highest cost shares due to their involvement in irrigated crops.

The main costs of the agricultural cooperatives were fodder and wages. A substantial portion of this feed cost is purchased concentrates: mixed fodder, sesame, cottonseed oil meal, husks, barley and maize are the most widely used types of concentrate components.

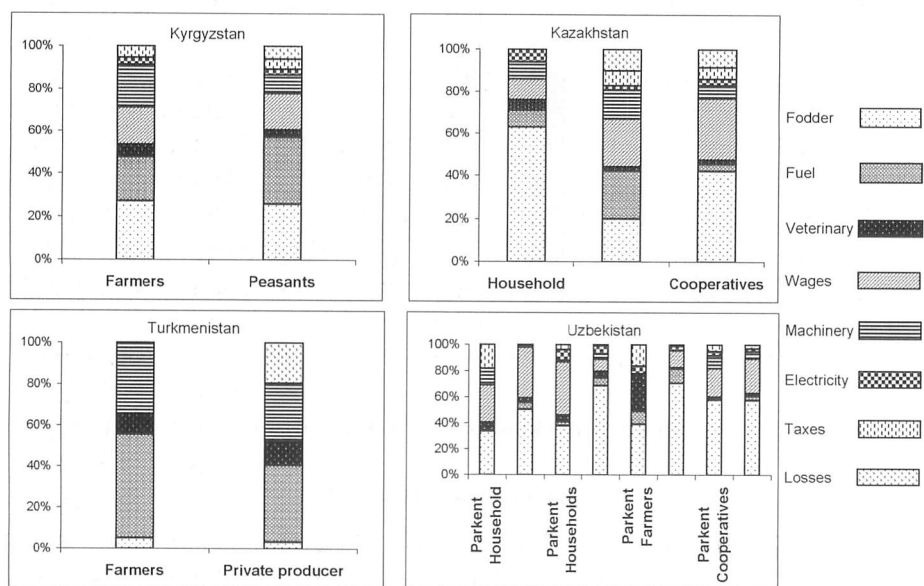


Fig. 3. The cost structure of surveyed sample farms in selected Central Asian countries.

Farm Income Structure

The composition of income for different farm types shows that sales of live animals are the main sources of income (about 40%) for household plot farm types both in Kazakhstan and in Uzbekistan, with the exception of those in Nurata area in Uzbekistan who reported pelts (shepherd households) and social welfare (non-shepherd households) as their main sources of income. The second most important source of income was the sales of mutton (25%) followed by milk and dairy (19%) in Kazakhstan, whereas in Uzbekistan the second most important source of income was milk and dairy (25%), followed by the social payments (21-23%). The contribution of wool, skin and pelts is very low (1-4%) except for the livestock-based households in Nurata region where skins and pelts were ranked first income contributor (26%), Cattle milk is a significant income source in Parkent household plots (23-25%) because of its proximity to the Tashkent market.

The income composition of the family and peasant farms in Kazakhstan differs from household farms in that the share of income from meat sales (close to 35%) is slightly higher than that from live animals sales (33%). The sales of live animal remains was the most important income source for family and peasant farms in other three countries ranging from about 50% to 90% of the income. This is followed by skins and pelts (16%) and meat (14%) in Uzbekistan, and cereals and meat sales in Kyrgyz Republic in that order. The higher share of meat sales in income indicates that private family and peasant farms have greater capacity of capturing the added value of slaughtered animals compared to the sales of live animals. The share of milk was low (5%) but it could increase in the future.

In Turkmenistan, private family and peasant farms generate 62% of income from livestock and 38% from crop production. Out of the income generated from livestock, the share of meat marketing represents 52%, live animal selling 34%, milk and dairy products 8%, pelts 5% and wool 1%. This indicates that farmers prefer to slaughter livestock and market meat rather than market live animals. In Kyrgyz Republic, fodder production is the most important source of income from crops 70%, other crops include melons 10%, vegetables 11% and others 9%. This shows that farmers produce fodder (such as alfalfa) not just for farm feed requirements, but also for income generation from direct sales. The non-existence of off-farm income may indicate lack of rural employment and slow adjustment of the former collective farm workers on the non-agricultural employment in rural areas.

The *Collective* farms can be distinguished into two types: those relying on grain production and those more oriented towards livestock production. The grain-oriented cooperative farms are those with large land resources in Kazakhstan and in Parkent area in Uzbekistan, generating about 30-40% of their income from grains. The livestock-oriented agricultural cooperatives are mainly those in Nurata district in Uzbekistan, with almost all of their income coming from livestock: 50% meat sales, 25% live animals, and about 20% skins and pelts. The importance of wool was very low below 6% in all surveyed farms. Overall, there have been greater diversity of farm income in the countries with the more advanced process of economic and institutional reform, namely, Kazakhstan and Kyrgyz Republic.

In summary, the sources of income for household plots, and private family and peasant farms are the sales of live animals, meat, forage crops, milk and milk products. In addition, some households depend on off-farm employment while others rely on social welfare. Agricultural Cooperatives mainly depend on grain crops, live animal and meat sales. The importance of pelts and wool as source of income has markedly decreased.

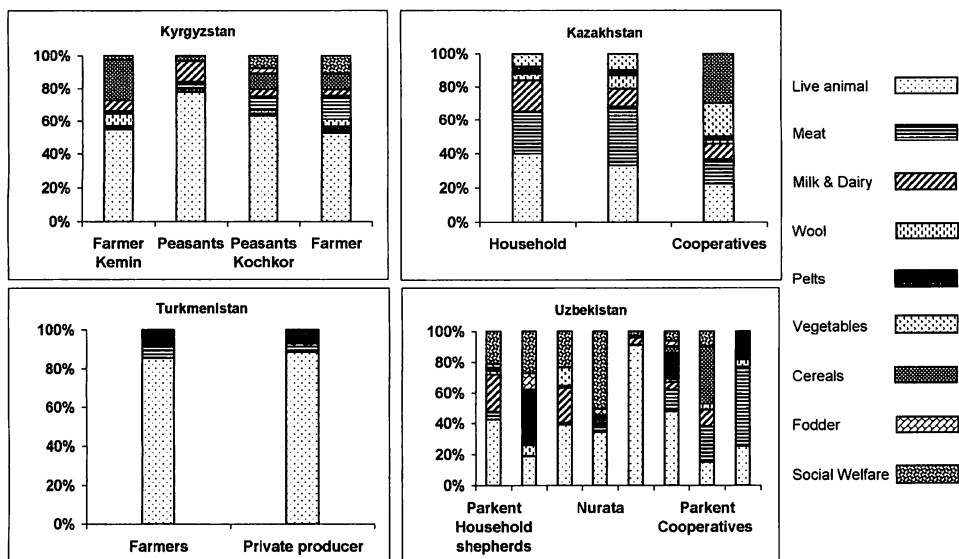


Fig. 4. Income structure of surveyed sample farms in selected Central Asian countries.

Several factors affect farm income. Among these are price fluctuations, market proximity, production diversification and government regulations. The seasonal fluctuation of prices affects significantly the income of farmers. Relatively higher prices for livestock products were observed in winter and beginning of spring and lower prices are observed in summer which is a season of high consumption of vegetables and fruits, whereas the demand for meat is high during winter, leading to high meat prices. The farmers who were able to market directly to the consumers or retailers or who were able to market added value products such as meat rather than live animal had higher income than farmers who sell to middlemen.

In Turkmenistan, individual farmers marketed about 83% of the live animals and 38% of the meat produced directly to retailers and consumers without middlemen. Small landless livestock producers mainly sell their meat to middlemen because of difficulties to access the market. Most of these producers are far from urban market centers and may sometimes use barter to trade their livestock for needed farm inputs.

In Uzbekistan, low market prices were perceived as major constraint to income generation. Farmers consider State regulations and shortage of buyers as factors causing low prices. State regulations also influences production and marketing of Karakul pelts and wool, which are required to be marketed through state processing enterprises that offer low prices and delay payment for long periods. Although the private sector is still in its early stage of development, it offers better market prices and does not delay payments.

MARKETING

The Central Asian countries have, since the collapse of the Soviet Union, entered a period of economic transition. During this transition, the newly independent states developed their own economic and trade policies and embarked on economic reform programs involving market liberalization, agrarian reform and institutional and policy reforms. One of the main effects of the economic reforms during the transition was the changes in agricultural marketing. As the highly integrated markets of the former Soviet Union has been dismantled by the new economic and political realities, traditional trade market linkages have disappeared.

The dismantling of the major agro-food complexes has resulted in the breakdown of traditional channels in domestic and regional markets. The degree of transformation from centrally planned to market-oriented economy, however, varied in different countries. This difference in degree of market liberalization and privatization of agriculture has determined the extent in which market can influence production and consumption patterns. However, new marketing system is immersing although at different rates in different counties depending on the stage on the economic and institutional reforms. Since the economic transitional period, demand and supply have increasingly become important in determining prices.

Market Structure

Most agricultural commodities are marketed through a marketing chain: *wholesale traders, processing enterprises, intermediate traders and retailers*. The wholesale traders mainly deal with wool, skins and Karakul pelts. Currently, wool is mainly destined at the local market, while the exports to Russia, China and Ukraine have dwindled. Pelts are also sold in local markets but there seems to be a demand from Russia. Milk is mainly for the local market. In most cases, wholesalers supply the products to processing enterprises, which also sell these products wholesale.

As a result of the changes in traditional market channels, large processing enterprises, which still remain as public entities, operate below full capacity due to the low pace in adjusting to market conditions, lack of cash to pay suppliers and lack of experience in marketing skills. It was estimated that only 5% of the milk processing capacity of the food complex in Jambul Province (near Almaty city) has been utilized in 1999, and 1.5% of its grain capacity has been used. Most of the product was sold as barter due to shortage of cash.

Similarly, processing companies have delayed the payment of 19 million soms worth of wheat production to a Cooperative farm (Boykozon) in 1999. Wheat is a national strategic crop and the farm has to sell it to the state at 25 soms per kg

while the market price is 70 soms per kg. Hence, there are important implications of the continued marketing through the traditional marketing channels. Intermediary traders buy products from producers and sell to processing enterprises or to consumers. These intermediaries often buy large number of animals in rural markets and sell them in larger urban markets. Processing enterprises, purchasing fresh products, process and sell them to intermediaries, wholesale or retailers. Individual farmers also process products and can be retailers. For example, farmers collect milk from neighbors, process it at home into various milk products and sell the products. Retailers can be producers (households) selling live animals, milk and dairy products in the markets, and at home or retail shops selling food stuffs.

In Uzbekistan, where milk processing companies are less developed, individual intermediaries and retail shops dominate the market. Small-scale intermediaries usually sell small quantities of products mainly produced by themselves in their own farms (and in some cases collected from their neighbors). They sell on the average about 20 liters of milk and 15 liters of yogurt (*kefir*) per day and some are specialized on milk, yogurt, and cream. The products are processed in home conditions. Packaging is basic and it has neither labeling nor health and contents information. About 26% of the interviewed milk traders (milkmen) have no refrigerators for storage of the products.

Medium-size intermediaries usually buy products from several producers and sell on the average 30 liters of yogurt and 30 kg of feta cheese (*suzma*) per day. They mainly deal with yogurt, feta cheese, cottage cheese, cream and butter. They also process products in home conditions. Again packaging lacks proper labeling essential consumer information. Processing companies buy milk of about 2-20 t/day, as a rule from agricultural cooperatives and farmers. Processing plant is equipped with milk processing technologies and quality of dairy products produced at the plant in most cases is better and has good package. Due to the technologies available, the processing company can offer more diverse products.

In the Almaty region of Kazakhstan, most of milk processing (about 60%) is handled by processing companies that sell to retailer shops and large food stores. There are four major food companies operating in Kazakhstan who are dominant players in the dairy market. These are:

- *Food Master*, the biggest milk processing company in the Almaty region, 75% of its products are sold in supermarkets, small shops and regional markets.
- *Zhiger*, the second biggest company which produces about 20% of dairy products in the region, it has good technology to produce high quality products.
- *Agroproduct*, it holds 5% of the regional market for milk and dairy products in the region which are marketed through companies small shops.

- *Adal*, produces 40 types of dairy products and has vertically integrated marketing approach with a dairy farm covering part of the supply.

In Uzbekistan, both individual traders and processing plants act as wholesale traders of meat. Retailers in most cases sell meat to consumers. The retailers are mainly butcher shops and individual retailers in the bazaars. Butcher shops and food stores have appropriate conditions for meat storage such as refrigerators and freezers, whereas individual retailers do not have such conditions. Unsold meat is marketed at lower prices.

In Kazakhstan, the intermediaries have established a network of butchers in Almaty city, where they directly sell meat. These intermediaries receive a marketing margin of 33% of the purchase price. There is indication of specialization of different traders on one specific product where they developed linkages with supply-retail networks. For instance, 22% of the intermediaries deal only with beef, 12% live animal, 44% trade only milk and dairy products, and 20% mutton. Farmers need market information in order to be able to negotiate traders with the right price. The intermediary traders selling perishable products - meat, milk and dairy products, select their suppliers based on product quality, commission rates and volume of supply, while those marketing industrial products skin and wool, use purchase prices and product quality as major criteria.

The marketing strategies that farmers use for different livestock products vary. In all studies areas, wool and pelts are marketed through middlemen. In some cases, like in Uzbekistan the government marketing agency is the sole buyer. Market channels for other products vary by location. In Kazakhstan, direct sales to retailers and consumers is the most common marketing strategy. Agricultural cooperatives marketed substantial livestock products (21-53% of live animals, wool and pelts and meat) through barter trade. Private farms used barter trade much less. Direct sales was also more frequently used by crop-based private farms in Turkmenistan. In Kyrgyz Republic, farmers mainly marketed their products through middlemen. In Uzbekistan, wools and pelts were marketed largely through middlemen; however, the shepherd households sold their wool and pelts to the cooperatives. In general, private farmers used middlemen more than the households which indicates an increasing development of private marketing channels. Direct sales to retailers and consumers is the preferred marketing for live animals and meat by all farm types. One exception is that the majority of shepherds a households marketed their live animals through the cooperative and middlemen which normally gives lower price.

Finally, milk and dairy products are mainly marketed directly to retailers and consumers or through middlemen. For both live animals, and dairy products, household farms generally sell their products to the middlemen and the cooperative, while private farms sell directly. This shows that private farms are more able

than household farms in capturing at least part of the marketing value of their produce. It also means the household farms are the once most affected by the market distortions that may result from the domination of a single buyer, for example, when the cooperatives have protected dominance over certain markets.

Seasonal Price Fluctuations

Price fluctuation affects farm income and creates risk for producers. Prices fluctuate with the season depending on the changes in consumption patterns and production cycles of different products. Data from the survey indicated that the demand for some of the dairy products (milk, butter and cottage cheese) are high in spring but as supply increases, prices fall. This is a preferred season for the consumption of these products as they are considered fresh. At the same, this is when livestock can graze on green rangelands. Prices are the lowest in summer which is explained by the fact that summer is unfavorable season for selling these perishable milk products without appropriate refrigeration. Figure 5 shows seasonal fluctuations of prices for milk and dairy products in the markets of Uzbekistan based on survey data collected from urban centers.

Producer prices for animals are lowest in summer when the supply is the highest. In autumn, animal weights start to drop as grazing becomes scanty. This has a

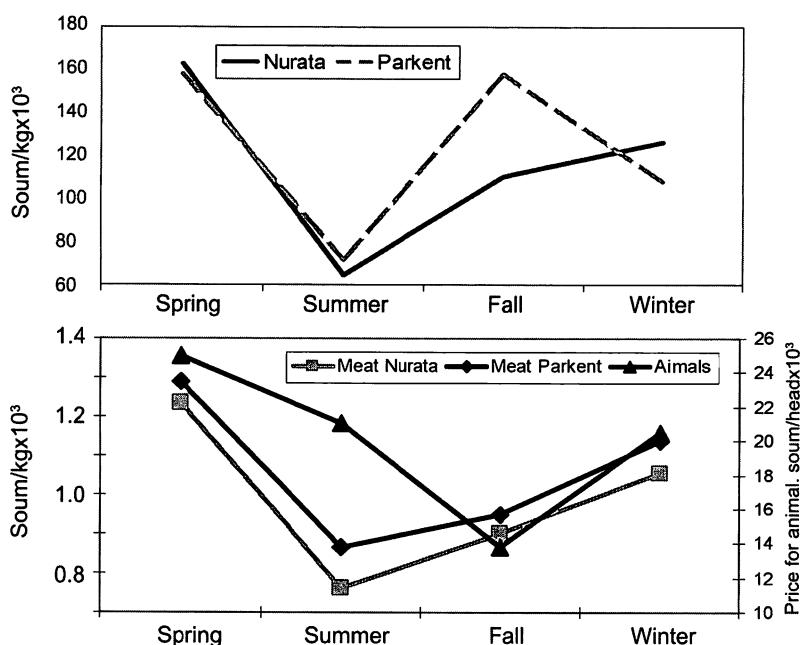


Fig. 5. Seasonal fluctuations of livestock and meat prices, Uzbekistan, 2001.

negative effect on producer prices. But in this season, farmers are preparing for winter and part of the stocks are sold for purchasing feed, hence increasing meat supply. However, this is also a season of weddings and celebrations which increases the demand for slaughter animal for festivity purposes. The net effects of these opposing factors is higher animal prices compared to the summer when body weight is better and supply is higher. The declining supply and lower animal weights continue into the winter while the demand for meat increases hence prices are highest in winter.

The marketing margins for middlemen fluctuate with prices: *higher prices means higher commissions*. Marketing margins also depend on product type, access to main markets (cities) and storage facilities. High price margins for live animals were reported in autumn when demand for live animals begins to grow due to the huge number of celebrations occurring during this period. Special seasons like the new year holidays and during celebration of sacred Ramadan month show highest consumption of meat products. The intermediaries' commissions on milk marketing include transport expenses (5-15%), processing (from 2% when it is processed at home up to 25 % in case of industrial processing), storage (up to 10 %), packing (only in case of industrial processing, from 5 to 25%). In the Almaty region study, the marketing margins for meat are estimated at 23-30%, fresh milk at 10%, and dairy products at 17%, except matured cheese which has 26% margin which associated with transportation cost.

Potential Demand for Sheep Milk Derivatives

In order to determine the potential for sheep milk derivatives in the market, intermediaries and consumers were asked about their perceptions of sheep milk and views on marketing. The potential for sheep and goat milk varies by country and by region. In Uzbekistan, 22% of the interviewed middlemen perceived demand for sheep milk and all those interviewed were willing to market sheep milk derivatives. They consider milk and yogurt of sheep and goats are in demand but not cheese and cottage cheese due to specific consumer taste preference.

Farmers are aware of the potential for dairy sheep. They consider the possibility of milking ewes if dairy types are introduced and market demand exists, but they also indicated the possibility of higher feed costs. In Narata district of Uzbekistan, which is major sheep breeding region, there is local experience in milking sheep. There were 29 respondents who sold sheep milk products. In this area, dairy sheep is viewed positively and currently ewes are milked mainly for home consumption. In Parkent District, where dairy cattle is well developed, local population milk goats mainly for home consumption. About 47% of the interviewed consumers in Parkent district and 88% in Narata district (Uzbekistan)

have tried ewe milk. Ewe milk and yogurt are demanded by the population in Narata and they are marketed during spring. Overall 69% of interviewed consumers in Uzbekistan are willing to try new ewe dairy products.

In Kazakhstan, fewer traders (8%) expressed positively about marketing sheep milk derivatives and half of them (5%) are unwilling to market new products like sheep milk derivatives. In this country, where the traders are more established with networks and specialized with specific products, there is very low willingness to trade new products. The potential for dairy sheep products are in doubt although some of the (41%) of the urban consumers expressed willingness to try! The consumer survey revealed variations in the consumers' perceptions of sheep milk derivatives in rural and urban populations. Rural consumers are willing more than urban consumers. This willingness was higher in Uzbekistan, Turkmenistan and Kyrgyz Republic and much lower in Kazakhstan.

CONCLUSIONS

The economic transition in Central Asian countries had profound impacts on the rural areas. The results of this study raised a number of issues related to live-stock production, marketing and policy. These issues raised in this study should guide further research and development initiatives in the livestock sector of the region. The main points summarized below:

Production

- Lack of forage is considered the most important limiting factor of livestock productivity. Many of the smallholder household farms and private family and peasant farms have limited feed resource-base (hay and rangelands) and this is a major factor restricting their options to reduce feed cost and increase farm income. These households do not access remote range lands due to their inability to organize and mount mobile grazing to long distances. However, increased access of common rangelands increases the conflict between large farms and small holders. Institutional arrangements to increase their access of remote rangelands and research on low cost feed rations will improve their productivity and must be a priority for further research.
- Surveyed farmers reported a number of animal diseases as main production constraints. Diseases caused by external and internal parasites, gastroenteritis, and respiratory diseases are common; cases of brucellosis were also reported. Livestock herders in Turkmenistan use remote grazing and they noted its advantages on reducing infectious diseases, particularly skin diseases. Tick-borne diseases are reported in the Central Karakoum area (Turkmenistan) where hot climatic conditions are favorable for such diseases.

- Private farms have difficulty in obtaining inputs such as farm machinery. Most machinery used is aged and inefficient in performing farm operations. The majority of farmers attributed reduction in forage production to lack of agricultural inputs, such as seeds and finances. Most farmers started to produce cash such crops as tobacco and sugar beet instead. There is a potential that farmers develop community-based organizations to cooperate in the acquisition of services and in marketing. This requires strengthening and capacity building of community-based organizations. Future research and development projects, therefore, should consider supporting community-based marketing organizations to increase farm income through improved livestock marketing.
- Credits for most farmers are difficult to obtain because of high interest rates and bank requirements that are inappropriate for farmers. Farmers do not have guarantors and property to be mortgaged.
- Lack of alternative off-farm employment. In the conditions of insufficient government support to agriculture and disintegration of the social infrastructure, the number of people employed in the agriculture sector has decreased significantly. The average wages of agricultural workers within the last 10 years dropped 6-fold; while the salary reduction in the industrial sector was much less. This leads to economic stagnation and poverty in rural areas.

Policy

- Agricultural policy is important factor that affect farmers choices and welfare outcomes. Monopolies still operate in some markets like that of pelts in Uzbekistan. Such monopolies and State regulation that depress producer prices can reduce profits, discourage private investment, and deteriorate the welfare of rural communities. Another policy that needs to be reviewed is the crop production quota requirements for wheat and cotton in Uzbekistan and Turkmenistan that limits farmers options to utilize high value crops that are demanded in by the market.

Marketing

- Markets face a problem of *government control, poor infrastructure and lack of private investment*. In the absence of effective institutional and policy support for agricultural and food marketing and processing, as well as of market information support services, farmers face difficulties in getting competitive prices for their products. Marketing is sometimes constrained by local monopolies that are often the only available option for farmers to purchase inputs and sell their produce.

- Product quality is an important factor in marketing and an important determining factor of sales and revenue. Marketing of perishable products need to be done in appropriate cooling and refrigeration systems for storage and transportation as well as clean environment for processing. Lack of investment in the marketing infrastructure and essential facilities cause deterioration of product quality, and reduce public confidence and profits. This is also critical as international food companies expand to these countries offering more popular brands.
- It was found in the marketing survey that many retailers of meat do not have appropriate conditions for meat storage - refrigerators and freezers. Some butchers and shops have appropriate conditions for meat storage, refrigerators and freezers. About 57% of the respondents indicated their willingness to pack and label the products if they have adequate resources and information.
- Consumers perceive that product quality can be improved by better storage facilities (refrigerators and freezers) better livestock breeding that produce products with higher fat content, improved processing and packaging (yogurt) high quality. Consumers also indicated their increasing awareness and preference for better packaging and labeling of products. The urban consumers in the Almaty region prefer the products with "good" trademark. There is a dire need for strengthening farmers-based organizations to improve the standardization and quality control of agricultural products in order to ensure that farmers do not loose out to imported products.
- There are marketing opportunities for different products at different markets based on season, product type and location. Improvements in livestock management such as strategic feeding and provision of feeding at specific times of the year can help producers target specific meat and dairy markets and increase farm income.
- The highest positive perception of sheep milk production was recorded in Turkmenistan (80%), followed by Uzbekistan (60%), but less so in Kazakhstan (10%) and Kyrgyz Republic (10%). Sheep milk products could, therefore, start in the rural areas where there is already experience. This could be later expanded to other areas. However, the development of this will depend on consumer tastes and preference, and prices. Cost of production, particularly feed cost, will play an important role in the success of dairy sheep products.

International Cooperation for Agricultural Research in Central Asia and the Caucasus

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ABSTRACTS

The agro-ecologies of the eight newly independent states located in Central Asia and the Caucasus (CAC) and the western USA have similar cropping systems, as well as shared problems. The goal of the project, International Cooperation for Agricultural Research in Central Asia and the Caucasus (ICAR), is to increase the sustainability of agricultural systems in both the U.S. and the CAC. The region is the center of origin for several crops important to the western US including wheat, barley, apples, alfalfa, grain legumes, onions, perennial grasses, lentils and chickpeas. Project benefits include access to plant germplasm and to biocontrol agents for major weeds, pests and diseases; access to a global network of scientists and knowledge; and development of common solutions to environmental degradation caused by agriculture, including wind erosion, salinization, and loss of biodiversity. Since July of 2002, a network of researchers, educators and agricultural stakeholders in the CAC and the USA has been developed. The 1st Central Asian Wheat Conference in Almaty, Kazakhstan was held in June 10-12, 2003 and attended by 250 researchers from around the world. Seed distribution of CIMMYT international nurseries in the US was coordinated through Oregon State University. 19 on-farm trials were established for wheat cropping systems in the CAC. Eight collaborative research grants among scientists from the US and CAC countries were begun. Agriculture

plays a key role in the CAC republic. The project will contribute to enhanced food security, economic growth and political stability throughout this strategically important region.

INTRODUCTION

Major problems and challenges face agriculture in the in the strategically important region of Central Asia and the Caucasus (CAC) and in the USA. Both regions must improve their production efficiency, respond to similar pest and disease problems and environmental constraints, and help their agricultural sector constituencies to better understand and respond to the evolving global marketplace, and to better access and use information and technology from around the world. They must also deal with increased competition for use of land, water and other production resources.

The US-funded project, “*International Cooperation for Agricultural Research in Central Asia and the Caucasus (ICAR)*” has the goal of promoting food security, economic growth, and political stability for people in the CAC. The year 2004 marked the beginning of the third year of funding for the ICAR project, which uses the methods of the US Land Grant system as well as the US Competitive Grants system to addresses major problems and challenges that agriculture faces in both regions of the world. The project enables US and CAC scientists to come together and conduct research that is of mutual benefit to the sustainability of agricultural systems in the CAC countries of Kazakhstan, Uzbekistan, Tajikistan, Turkmenistan, Kyrgystan, Armenia, Azerbaijan, and Georgia, as well as in the US.

In addition, a new generation of US and CAC researchers are working to address problems of mutual and reciprocal interest, to build enhanced capacity and long-term linkages. For reasons that will be described below, the US and the CAC countries share common environments, cropping systems, and environmental constraints. Research that is conducted jointly will utilize the substantial scientific expertise that exists in *plant germplasm*, *microbial biodiversity*, *soil science*, *conservation agriculture*, and *water utilization* to improve food security and sustainability of cropping systems in both parts of the world.

Funding and Administration

The project is funded through a special grant from the United States Department of Agriculture, Cooperative State Research Education and Extension Service. The USDA-CSREES is the primary US federal funding arm for research that enhances agriculture, the environment, human health and well being, and communities (<http://www.reeusda.gov/>). From the US perspective, continued development of strong, internationally focused agricultural research programs at

land grant institutions is an essential component of US competitiveness. Access to the wealth of relevant information, genetic materials and technology being developed around the world is crucial to sustained US leadership. Also, since the end of the Cold War, a new generation of US scientists has taken over leadership of US agricultural programs, but have had limited opportunities for "hands-on" international participation. This project provides such opportunities.

The program is administered by US Land Grant Universities and the International Maize and Wheat Improvement Center [*Centro Internacional de Mejoramiento de Maiz y Trigo*] (CIMMYT). Project planning is led by Washington State University (WSU), South Dakota State University (SDSU) and CIMMYT. Other Land Grant universities that are currently involved include University of Idaho, Kansas State University, University of Nebraska, and Oregon State University.

The Land Grant system in the US represents a unique system in higher education. It was founded in 1862 in order to provide opportunities for education to large numbers of people in liberal studies and industrial and agricultural sciences. *An important and continuing component of the land grant system is the integration of research, education, and outreach or extension.* That integration ensures that research findings are disseminated widely through teaching and outreach activities to the people who will benefit most. This aspect has been lacking in most research institutions in the former Soviet Union. The focus on agricultural and environmental research, extension, and education that this project embodies makes it a natural component of the Land Grant university system.

Collaborative agricultural research works best when countries have similar agro-ecological zones (Pardey and Beintema, 2001). The latitudes, agroecologies and production environments of the CAC and the US share remarkable similarities that have resulted in similar cropping and production systems, as well as shared problems and constraints. Wheat is produced in both regions between the 40th and 50th north latitudes (Fig. 1). Climates are similar with drought and temperature being the main production constraints. In Central Asia, although 83% of the land has a potential growing degree period of greater than 180 days, lack of moisture limits growth to less than 120 days on 96% of that area. While a much higher percentage of the North American continent is free from moisture and temperature constraints, this does not hold true for the western wheat production region.

In Central Asia, salinity limits growth in 37% of the arable land (Fischer et al., 2000). Both regions suffer from land degradation and desertification. In the CAC, land degradation has occurred because of overgrazing, salinization and water erosion on irrigated lands and wind erosion on plowed rainfed lands. In North America, the same is true and wind erosion continues to be severe even after the

hard lessons of the Oklahoma “Dust Bowl” in the 1930s (Dregne, 1986). Formerly productive land is lost to agriculture and yields are declining on remaining acreage.

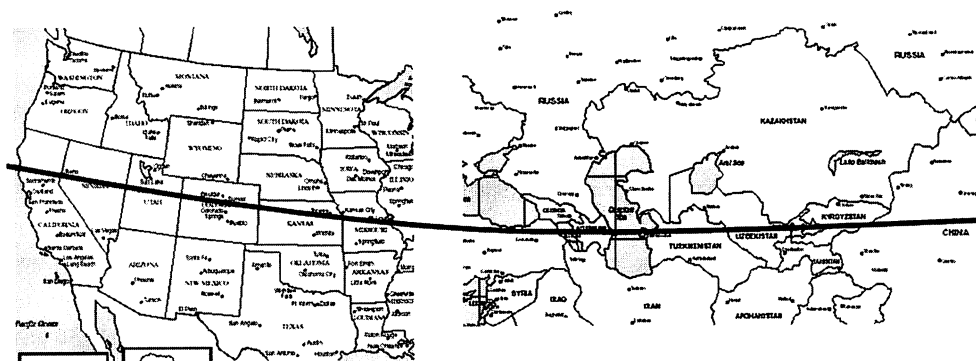


Fig. 1. Side-by-side maps of Western US and Central Asia and the Caucasus. Line marked is the 40th north parallel. Areas are only approximately to scale.

The CAC region coincides with two of Vavilov's centers of origin, the Central Asiatic Center and the Near-Eastern Center (Vavilov, 1949.) Although Vavilov's original centers of origin have been modified, the CAC is the center of diversity for a multitude of crops important to the economies of the Pacific Northwest, the Dakotas, Kansas, Nebraska and other US states. These include wheat, barley, apples, oats, alfalfa, grain legumes, onions, garlic, cool-season perennial grasses, lentils and chickpeas (Vavilov, 1949, Harlan, 1975). Environmental hazards and development are threatening remaining communities of indigenous plants. During the Soviet period, countries of the CAC participated in the system of genetic resource centers organized through the Vavilov Institute. Since 1990, those institutions have been nationalized and are autonomous, often without enough funding to maintain and preserve their collections. *Ex situ* and *In situ* germplasm collections are in danger of deterioration and loss.

Biological control agents are also of interest. Central Asia is home to some of the worst weed pests in the North American wheat cropping systems, including cheatgrass (*Bromus tectorum* L), Russian thistle (*Salsola iberica* Sennen & Pau), jointed goat grass (*Aegilops cylindrica* Host), and wild oats (*Avena fatua* L). Microbial and other genetic materials from the region show great promise in

controlling disease and insect pests. Testing and utilizing such agents and materials will reduce our dependence on chemicals and cut production costs.

The eight republics of the CAC face many of the same environmental problems that the US does, yet some are much more severe. Agricultural production systems are low in productivity and sustainability, especially the wheat production systems that affect food security. Since agriculture is a primary contributor to economic development in the CAC republics, these problems threaten economic and political stability in these important but fragile countries as they emerge from former Soviet governance. They also affect US agricultural markets, constraining the CAC populations as potential consumers of US agricultural commodities, inputs and services.

Wheat is a major focus of this proposal, since it is of equally high priority to both CAC and US partners. Wheat occupies approximately 16.5 million ha in the republics of Central Asia and the Caucasus, with Kazakhstan as the most important producer. Under the centrally planned economy of the former Soviet Union, only Kazakhstan had an important assigned role in wheat production. The other CAC republics were mandated to specialize in the production of cotton, vegetables, fruits, and other crops for use within the Soviet Union, and usually imported their wheat from elsewhere in the USSR. Since independence, these nations are now addressing their own food security needs, while diversifying and identifying new areas of comparative advantage. Wheat has become a shared priority commodity.

The transition from a the protected markets and commercial ties within the Soviet Union to global markets has been difficult for the CAC countries. In the early years of transition to market economies, food output decreased by 15-45% and population increased, with the exception of Kazakhstan. As a result, per capita food consumption decreased 15-45%. Future food needs exist for both urban and rural populations. Currently, 25-50% of the population live below the poverty line, while 50% of poor people live in rural areas, where farming is the primary link with a fragile environment. Access to high quality water is a major concern, and drinking water needs will increase. Water misuse and scarcity is a threat to human health, food security, and ecosystems. Addition comments on countries in the CAC follow:

Armenia

This country's borders are restricted from the outside world by Turkey and Azerbaijan. Armenia relies on its own production and aims to reduce food imports. The fertile valleys can increase yield substantially once the new technology and varieties reach the farmers. Stronger agriculture and research will help to keep people in the country and reduce migration. Non-governmental (NGO) funded projects like the Armenian Technology Group have made tremendous efforts to

bring better wheat varieties with some success, but need assistance from the projects like ICAR to develop better local capacity to identify, test and promote varieties and technologies (USAID, 1999).

Azerbaijan

Despite the fact that Azerbaijan witnesses continuous improvement in crop production, it is still far from meeting the domestic demand other than potatoes and fruits. Agriculture, research, extension and newly established private farms remain a high priority for the government. The World Bank funds a Privatization Support Project that runs its own competitive grant system for large-scale extension efforts. The grants offered by ICAR project aim at the research agenda not covered by the World Bank, although the two systems are very complimentary. In addition, ICAR gives an important opportunity for linkages with US universities.

Georgia

The mild climate of Georgia and moderately high quality soils result in good potential for Georgia to be competitive in a variety of agricultural markets. Market development will probably focus on grapes and other horticultural crops (Herron and Lee, 2001). Even so, wheat is the primary food of the rural poor. Wheat production in Georgia is an example of how the government, along with many donors, cannot develop sustainable local cultivation of seed that meets the demand. If invested locally, the amount of money spent annually to import seed would allow the production of sufficient seed through the development of machinery, infrastructure, and technology. The ICAR project relies on local expertise and jointly develops capacity in the country. Georgia already benefits from the modern US wheat varieties grown in the country. It also has untapped reserves of wild wheat relatives which could be beneficial for the global community as well as a great store of biodiversity for several important plant species.

Kazakhstan

Kazakhstan is the wealthiest of the Central Asian Republics due in part to its oil and gas resources. Even so, 30% of the people live below the poverty line and inequities continue to grow. The president of the country publicly announced in October 2002 that development in the following three years will focus on agriculture and rural areas. This has already been reflected in the government budget and new policies. The research system is also going through a fundamental restructuring. For the country with the highest arable land and priority placed on agriculture, the assistance of a project like ICAR is essential. Interest in ICAR on the part of the local National Agricultural Research Systems (NARS) has been high.

Kyrgyzstan

Regionally, the country has the highest share of its gross domestic product (GDP) in agriculture. The government realizes that the stability and the livelihood of rural population depend on agricultural and rural development. Its geographic location at the headwaters of major river systems in Central Asia enable it to affect critical and sensitive issues such as irrigated agriculture, electricity generation, and the environment in the downstream countries of Central Asia. The agricultural research system, unlike in Kazakhstan, does not have strong partnership relations with the advanced research institutions in other countries and the cooperation offered through ICAR is vital.

Tajikistan

Tajikistan has the lowest per capita gross domestic product from among the former Soviet republics. Only 8-10% of the land is arable. Cotton is the primary cash crop and acreage has been expanded as a result to the detriment of food security. Political and economic transition was complicated by a civil war from 1992-1997 creating poverty for 60% of the population (CIA, 2003). Despite the epidemic of Yellow Rust (*Puccinia striiformis*), a dangerous disease that affects a substantial amount of wheat during wet years, a resistant wheat variety from Kansas, "Jagger", along with CIMMYT-derived wheat has kept the grain production relatively stable. The importance of these varieties for rural populations and their daily life is difficult to over-estimate. Because of the mountainous terrain, Tajikistan has great diversity in climate and soils as well as good water resources. The plant diversity within the mountainous regions of Tajikistan should be explored and utilized for the benefit of humankind.

Turkmenistan

Turkmenistan is largely desert, with intensive irrigated agriculture in the oases. The main crop is cotton and Turkmenistan is the 10th largest cotton producer in the world. Poverty is widespread, privatization is limited and the government policies have resulted in almost complete isolation of Turkmenistan agriculture and scientists. Assistance and cooperation from ICAR is one of the few connections that Turkmen agricultural scientists have with the outside world. Turkmenistan has extensive hydrocarbon and natural gas reserves that can be exploited but transportation difficulties exist and the government has not been responsive to a market-oriented reforms (CIA, 2003)

Uzbekistan

Water remains the key to sustainable production of crops in Uzbekistan. The government has maintained or increased central planning for agriculture resulting in rigid, over-regulated policies for the farmers. A significant concerns for Uzbek

farmers is how to grow crops with limited, poor quality water. The population pressure in rural Uzbekistan demands production increases despite the inefficient policies. Poverty is estimated at 50% of the total population although actual figures are not available. The weak research system may collapse if left alone without support from projects like ICAR and involvement of international research communities.

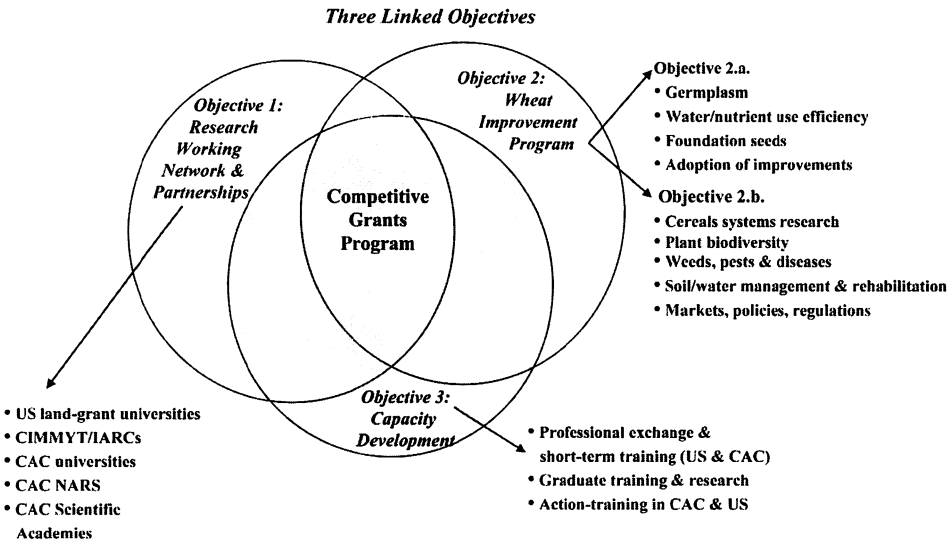


Fig. 2. Relationships among the three objectives for the project: International Collaboration for Agricultural Research in Central Asia and the Caucasus.

ROLE OF ICAR

In order to meet the challenges outlined above, ICAR has adopted a three component approach to enhance agricultural research and its impact on food production (Fig. 2):

1. Establish a network of US, CAC and other partners in agricultural research, education and sector development engaged in solving problems of importance to the US and the CAC.
2. Develop and conduct collaborative research to increase sustainability of wheat-based cropping systems, to protect and promote use of plant and microbial biodiversity and to facilitate adoption of improvements resulting from this research. This objective includes outreach to local communities in a manner similar to that of the US Land Grant system.

3. Strengthen human resources and institutional capacity in the CAC and in US land-grant universities to achieve the above research objectives in the near-term and sustain mutually beneficial international collaborations into the future.

ICAR components, goals, and current progress are described in more detail below:

- 1. Develop a pilot working network of US, CAC and other partners in agricultural research, education and sector development engaged in solving problems of importance to the US and the CAC.**

Projects of this type require scientist-to-scientist personal relationships and interactions to form a network between the CAC and the US so that research interests can be identified, shared and trust can be developed. This network has been initiated and includes US Land-Grant universities, agricultural universities in the CAC, national and international research organizations, the private sector and other agricultural stakeholders in the US and CAC. Communication is being facilitated through various methods including face-to-face conferences, individual exchange visits, conference calls, and use of electronic communications. Since June of 2002, multiple conference calls involving US partner universities, the private sector, CIMMYT headquarters and the CIMMYT program in CAC have been conducted to clarify project objectives, plan activities and ensure implementation mechanisms are in place. These conference calls have saved funds from the travel portion of the budget that are now being used for individual scientist exchanges.

The CAC-ICAR project office has been established using the CIMMYT office in Almaty, Kazakhstan as the base, under the direction of Dr. Alexei Morgounov. Associated administrative support systems have been established and refined between the WSU, SDSU, and CAC-ICAR offices and with CIMMYT headquarters in Mexico. WSU serves as the primary contractor with USDA-CSREES. The US university partners have subcontracts with WSU for access to funds. Funds are distributed in the CAC through the CAC-ICAR office in Almaty.

The project website: (http://www.ip.wsu.edu/projects_partners/ICAR/ICAR.html) for the ICAR project partners has been developed. The web site has been translated into Russian. Potential project partners from the CAC region, including agricultural research institutions, agricultural universities, academic institutions, and NGOs, have been identified and points of contact for communication established. A periodic newsletter publication in English was initiated by the WSU-ICAR office and sent out electronically on a monthly basis from June through October 2003. The newsletter will be continued on a quarterly basis.

Two project initiation and coordination meetings were conducted in October 2002 in Tashkent, Uzbekistan for Central Asian participants and in Tbilisi, Georgia for participants from the Caucasus. Those meetings were used to present the project, its objectives, and activities, and discuss the priorities and the implementation mechanisms. Forty-five (45) and 30 participants from Central Asia and the Caucasus, respectively, attended the meetings. The priorities for the grant projects were defined, the communication channels established and the project implementation mode discussed and agreed upon. Priority research areas were:

- *Agronomy - conservation tillage*, soil fertility, erosion control, permanent beds, increasing yield potential, water use efficiency.
- *Integrated pest management* - weed control, insect control,
- *Alternative crops* - forages, oilseeds, and legumes.
- *Plant breeding* - winter wheat, barley, maize, crosses with wild relatives, yellow rust resistance, grain quality, resistance to salinity, drought resistance, low-input adaptation.
- *Early generation seed production*: foundation seed production, multi-location yield trials,
- *Economics and marketing* - economic assessment of new technology, establishing grain quality standards, development of Central Asia economic zone, credit to farmers, economics of water use.
- *Conservation of biodiversity* - gene bank establishment, collection expeditions, regional and international cooperation.

Those meetings were also attended by representatives from the German Technical Cooperation Agency (GTZ) and non-governmental organizations currently operating in the region. Leveraging funding from this project, with funding from others has been a useful mechanism to use limited project funds efficiently.

The First Central Asian Wheat Conference was held in Almaty Kazakhstan, June 10-13, 2003, sponsored by CIMMYT; WSU; the Ministry of Agriculture of the Republic of Kazakhstan; The International Center for Agricultural Research in Dry Areas (ICARDA); GTZ on behalf of the German Federal Ministry of Economic Cooperation and Development; the Global Forum for Agricultural Research (GFAR); the US Agency for International Development (USAID); Winrock International, USA; and the Food and Agriculture Organization of the United Nations (FAO).

There were 244 participants and 22 invited guests from 28 countries of Central Asia and the Caucasus and abroad including Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Armenia, Azerbaijan, Russia, Ukraine, Turkey, Iran, Afghanistan, Pakistan, India, Nepal, Philippines, Taiwan, Jordan, Canada, USA, Italy, France, Great Britain, Denmark, Mexico, Syria, Czechia, Hungary, and Romania.

For several of the participants, this conference marked their first trip to Central Asia.

The participants discussed issues concerning the current status of research on wheat and current priorities in breeding, seed production, modernization of wheat production technologies, the challenges in the area of developing new approaches for promotion and stabilization of wheat yield and grain quality as well as the prospects and benefits from international cooperation regionally and globally.

As a result of the conference, several joint cooperative programs addressing wheat genetics, breeding, biotechnology and agronomy were discussed and approved. Because agricultural problems follow geographical rather than political boundaries, the focus of the regional group was expanded to include western China, southern Russia, and Siberia. The following group discussions were reported:

- The *Yellow Rust Regional Network* was recommended to continue the successful cooperative work on monitoring the pathogen population and evaluation of germplasm for resistance and more emphasis on rapid multiplication and promotion of new varieties resistant to this pathogen.
- The *Wheat Grain Quality* group discussion recommended establishing a regional framework for evaluation of bread-making quality of new wheat varieties. The framework should take into account existing facilities and improvement of the quality labs in the countries of the region.
- The *Winter Wheat East European Regional Yield Trial* (WWEERYT) shared the progress achieved over the last five years and stated that the trial is very effective mechanism of germplasm exchange among the countries of Central Asia, Eastern Europe and USA. The recommendations of the group discussion focused on improving the efficiency of the trial and technical aspects of germplasm exchange.
- The *Kazakhstan-Siberia Network on Spring Wheat Improvement* recommended development of uniform methodology and more emphasis on coordinated evaluation of germplasm for important traits in order to continue to conduct collaborative research uniting 14 breeding programs from North Kazakhstan and Siberia.
- A workshop on application of biotechnology in wheat breeding resulted in identification of priorities and potential areas of collaboration in the region. The project proposal will be prepared for submission to potential donors.
- The pre-conference FAO supported workshop "Explore on-farm" developed a set of pamphlets adapted for the conditions of the region, which provide the guidelines for planning and implementation of the on-farm experiments. The pamphlets will be available in Russian to all interested parties.

- A second Central Asian Wheat Conference is planned for in Kyrgyzstan for the summer of 2006.

Three years into the project, the research network is operating, not as a formal structure but rather as a mechanism to facilitate interest-based communication. In this respect the project activities reached the objectives by making the project known and establishing the communication channels. Future activities of the network will emphasize more formal arrangements. A periodic newsletter publication in Russian and in English is under consideration, in both electronic format and in hard copy since not all the scientists in the region have free access to the Internet. More formal representation from the CAC on the project steering committee is also desired.

2. To develop and conduct collaborative research to increase sustainability of wheat-based cropping systems, to protect and promote use of plant and microbial biodiversity, and to facilitate adoption of improvements resulting from this research. This research is subdivided into two interacting competitive grant programs.

A. The first grant program focuses on the funding of on-farm research trials following priority objectives in wheat cropping systems relevant to the CAC and US to:

- Improve wheat germplasm development;
- Improve water and nutrient management;
- Produce high quality foundation seed; and
- Facilitate adoption of improved varieties and technologies through demonstration in on-farm trials.

Germplasm improvement and evaluation is largely conducted through the CIMMYT regional nurseries. The ICAR project funds the multiplication and distribution of those nurseries to scientists in the US through Oregon State University. The WVEERYT and the *Facultative and Winter Wheat Observation Nursery* (FAWWON) were increased under quarantine and distributed. Although the exact names of the nurseries are under review, their increase and distribution will continue in order to meet the goals of distributing wheat germplasm worldwide to the wheat improvement community for assessment and for use in local crop improvement efforts. In 2003, Oregon State received 63 lines from CIMMYT-Turkey for quarantine seed increase to be shipped to 9 US cooperators in the fall of 2004. In previous years, quarantine seed increase was performed for up to 300 lines in the FAWWON for distribution to 40 cooperators in North and South America. It is our expectation that the nursery will resume for the 2005 crop year.

Competitive small grants for on-farm activities were initiated to demonstrate and promote sustainable wheat production technologies in the CAC. The requirements for the financial and technical reporting were developed and distributed to the project participants. The first call for the winter wheat proposals was made in September 2002. Based on evaluations of the 32 projects received, 14 projects in 7 countries were approved for funding. The call for proposals for spring wheat in Northern Kazakhstan was made in February 2003. Eleven proposals were received and 5 were supported for funding. The second call for winter wheat proposals was made in September 2003. Sixteen proposals were received, 14 were supported for funding. Six of those supported for funding were continuing projects that were funded in 2003. Project evaluations were conducted in the spring and summer of 2003 and upon project completion in September 2003.

The projects have focused on comparison of winter and spring wheat cultivars under local conditions; the demonstration of bed planting technologies; determining and demonstrating optimal fertilizer, herbicide, and fungicide inputs; assessment of alternative rotations in spring wheat, and triticale as a feed crop. Outreach to local growers is an important and necessary requirement for these projects. Field days were held for each project to demonstrate technologies to local farmers and a final report was generated in both Russian and English. The English version, along with photographs will be published in the Annual Wheat Newsletter (AWN) <http://wheat.pw.usda.gov/ggpages/awn/>. The Russian version will be made available on CD to cooperators in the CAC.

After one full cycle of these on-farm projects, the following impressions have been gathered:

- The projects raised considerable interest among the researchers to work directly with farmers. The technologies for demonstration cover a wide range of subjects and will certainly improve the production and productivity in the target environments. Farmer participation was good.
- The project did not reach all potential collaborators, and the proposals were limited to research institutions and universities. The local NGOs, the Farmer's Associations, and the private enterprises should be targeted in the future as they also can conduct efficient work with the farmers.
- Reflecting USSR practices and experiences, the quality of many proposals was not as high as desired. A workshop in western-style project, proposal preparation would be well justified, perhaps, in conjunction with regional planning efforts.
- Development of a clear mechanism and criteria for project monitoring and evaluation was completed by spring 2003. The criteria for project selection was more clearly defined in 2003 and more widely circulated.

- Because of the multiple years required for agricultural research, we will modify this component to include multiple-year trials as a part or whole of the on-farm research activities.

B. The second grant program funds collaborative research between US and CAC scientists that address the following objectives:

- Enhance sustainability of production systems through improved soil and water management and soil fertility improvement;
- Improve control of weeds, pests and diseases in wheat and other important cropping systems in the US and CAC;
- Safeguard and promote the utilization of plant and microbial biodiversity originating in the project countries;
- Assess constraints and help foster the development of an institutional environment in the CAC that supports free-market trade, including market development and appropriate agricultural policies and pricing mechanisms. This will also foster opportunities for US agribusiness in the CAC.

Collaborators identified seven major priorities for this project component during the course of earlier meetings in Tashkent, Uzbekistan and Tbilisi, Georgia, in October 2002 (priorities were listed above). The priorities are broad and reflect the needs of the region as well as the interest of the US universities. The detailed call for proposals was developed based on the USDA-CSREES proposal format, translated into Russian and widely circulated in the region. It was anticipated that 5-6 projects would be supported for two years with the annual budget of \$10,000-15,000 each. A total of 120 pre-proposals were received, representing all CAC countries and a spectrum of the identified priorities. The number and quality reflects the great interest from the research groups in preparing these proposals and participation in the program.

The number of pre-proposals greatly exceeded the numbers anticipated, and taxed the translation capacity. For the first step, only the Proposal Summaries were translated and a short list of 30 proposals was selected based on quality of the research, subject matter and geographical diversity.

Those 30 proposals were translated in full into English. Proposal summaries from the 30 proposals were sent to US partners to seek interested collaborators. Eight collaborators were identified. Funding for the proposals was approved by the USDA-CSREES in Jan 2004. The final proposals recommended for funding are:

- “Conservation and Use of Wild Kinds of Cereals in Breeding in Armenia.”
Principal Investigators: M. Gulkhasyan (Armenian Agrarian Academy, Armenia) and G. Brown-Guedira (USDA-ARS Manhattan KS, USA).

- “Virulence of Yellow and Brown Rust Pathogens and Evaluation of Wheat Varieties.” Principal Investigators: Z. Sikharulidze (Research Institute of Plant Immunity, Georgia) and K. Gill (WSU-USA).
- “Technology of Winter Wheat Yield Improvement by Introduction of Alternative Leguminous Plant Chickpea.” Principal Investigators: T. Avtandil (Mtsheta Breeding Station, Georgia) and S. Machado (Oregon State University, USA).
- “Maize Hybrid Development for Georgia Using CIMMYT Breeding Material.” Principal Investigators: Z. Jindjiadze (Georgian Research Institute of Farming, Georgia) and D. Gustafson (South Dakota State University, USA).
- “Spring Wheat Protection from the Hessian Fly Based on Resistant Varieties.” Principal Investigators: G. Zharmukhambetova (Scientific research institute of plant protection Kazakhstan), K. Kidwell, (WSU, USA) and E. Souza (University of Idaho, USA).
- “New methods of Soil Conservation Farming and Crop Diversification.” Principal Investigators: Z. Kaskarbayev (Research and Production Center for Grain Farming, Kazakhstan) and H. Woodward (South Dakota State University, USA).
- “Inheritance of Resistance to Yellow Rust in Winter Wheat.” Principal Investigators: A. Kokhmetova (Institute of Plant Physiology, Genetics and Bioengineering, Kazakhstan) and X. Chen (USDA-ARS Pullman WA, USA).
- “Study and Introduction of Leguminous Plants in Turkmenistan.” Principal Investigators: R. Babadjanov (Scientific Research Institute of Agriculture and Water of Turkmenistan, Turkmenistan) and F. Muehlbauer (USDA-ARS Pullman WA, USA).

The most challenging part of this grants program is now beginning. US collaborators are currently contacting their CAC counterparts to arrange for site visits and other forms of information exchange. Now that the first round of grant proposals has been reviewed and funding has begun, findings and recommendations are as follows:

- The proposal format (based on the US CSREES proposal format) facilitated proposal review.
- Proposals were generally of high quality, although some improvement in proposal development is still necessary. The higher number of proposals approved from Georgia and Kazakhstan reflects previous training in proposal development that has occurred in those countries.

- The large number of proposals received was somewhat overwhelming, but the list of proposals received is a good survey of research interests at institutions in the CAC.
 - Use of the proposal summary as an initial screening tool was a good method of prioritizing translation activities and of seeking interested collaborators.
 - We plan to develop the next round of collaborative research proposals by asking US scientists for their research interests, matching them with CAC scientists with similar research interests (from our list of proposals submitted in the first round), and encouraging that proposals be developed jointly.
 - It is premature to evaluate accomplishments of individual research projects because the funding is just being disbursed.
 - The application of the US competitive grant system in the region has already changed the way of thinking of many scientists and set different standards for their work.
- 3. The third objective is to strengthen human resources and institutional capacity in the CAC and in US Land-Grant universities to achieve the above research objectives in the near-term and sustain mutually beneficial collaboration into the future.**

This includes participation in the research partnership network; professional exchange and short-term training (US, CAC); and graduate education and research. The project has identified specific individuals and organizations that have demonstrated their interest and commitment to be involved in the project through the competitive grants program. The initial activities confirmed the need to enhance English language capabilities among CAC collaborators in order to enhance their ability to communicate with US scientists, to access Western literature, to become familiar with international standards, and to benefit from English-based training in the US and elsewhere.

CAC scientists who are collaborators in the funded proposals from Objective 2b will be enrolled in local English language training suitable to their current abilities. We have decided not to concentrate on Russian or local language training for US scientists for two reasons: 1.) Countries are using their own languages as well as Russian and funds are limited. 2.) English is the primary scientific language. Russian or local language capability is required for our outreach activities and we are able to provide translation services for this effort through the CAC-ICAR and WSU-ICAR offices.

In order for collaborative research to be fully successful communication requires a common language and shared technology. A second area of improvement is in computer technology and access to the internet. Funding for computers

was a feature of every project that was funded for the collaborative research projects.

The funding for this objective does not begin to meet the demand. The need for and benefits from additional resources for capacity development have been identified and leveraged external to this grant. As the project develops and the linkages between the individual scientists are established, mutual visits and training in the United States will be expanded. ICAR is actively collaborating with other programs and activities in the region that are being carried out by US Land Grant Universities, CIMMYT, ICARDA, USDA and others. WSU and CIMMYT, are among the organizers of the International Caucasian Conference on Cereals and Food Legumes to be held in Tbilisi, Georgia, from June 14-18, 2004. US-based ICAR scientists attending the conference will be able to establish connections with their CAC counterparts. In addition, funds are being leveraged through other organizations active in the region, including:

- *Winrock International*. Purpose: innovative approaches in agriculture, environmental protection, renewable energy, leadership development, and policy to increase long-term productivity, equity, and responsible resource management (<http://www.winrock.org/>). Funded US visits to southern Kazakhstan farms, Summer 2003.
- *The FAO*. Purpose: helping to build a world without hunger (www.fao.org). Funded a study trip for Kazakh representatives to view US and Canadian conservation tillage procedures, October 2003.
- *The USDA-Plant Exchange Office*. Purpose: to collect, document, distribute, evaluate, enhance, and preserve the genetic diversity of economic plants important to U.S. and world agriculture (<http://www.barc.usda.gov/psi/ngri/peo.htm>). Funded an exploration and collection trip for wild wheat and barley relatives in Eastern and Central Kazakhstan, Summer 2003 and 2004.
- *The International Science and Technology Center (ISTC)*. Purpose: providing weapons scientists from Russia and the Commonwealth of Independent States new opportunities in international partnership in non-weapons related scientific activities (<http://www.istc.ru/>). Funds US-CAC collaborative research throughout the region.
- *The ARS-Former Soviet Union Scientific Cooperation Program*. Purpose: to link USDA scientists with scientists in the Former Soviet Union to collaborate in the ISTC program (<http://www.oirp.ars.usda.gov/menu.htm>). Funds research in Kazakhstan, Russia..

- *The US Civilian Research and Development Foundation*. Purpose: A nonprofit charitable organization that promotes scientific and technical collaboration between the United States and the countries of the Former Soviet Union (<http://www.crdf.org/>). Has funded research throughout the region.

Too often, similar agencies discover themselves conducting similar work in developing countries. Even with the limited funding available through the ICAR project, the network of relationships that has been and continues to build among CAC scientists, with those in the US and the world will result in clear priorities and coordinated activities to the benefit of agriculture. This project has a key role in the establishment and maintenance of those relationship networks.

PROJECT ACHIEVEMENTS

In summary, to date, the ICAR project has accomplished the following:

Research Network

- Collaboration, coordination and integration of regional wheat breeding programs are improved.
- Collaboration among US Land-Grant institutions, CIMMYT, other International Agricultural Research Centers, and the USDA and CAC research and educational institutions has increased and are responsive to their clients, farmers and agribusiness.

Collaborative Research

- The CAC wheat seed foundation and distribution nursery is established in the US and germplasm is being disseminated. This is conserving CAC germplasm, assessing its performance at various US Land-Grant test sites and enabling its utilization it for variety improvement in the US and CAC.
- New wheat varieties adapted to CAC conditions are selected for immediate release and for seed multiplication and for testing in the US (see above).
- Genetic resources for priority commodities, weed and plant pathogens and potential biocontrol agents are further characterized and results used to conserve genetic resources and to improve agricultural productivity in the US and CAC.
- Improved methods for soil rehabilitation are developed, tested and introduced in US and CAC.
- Selected studies to identify market, policy or institutional constraints and recommended actions are completed and shared with decision-makers. For

example, studies on cost and availability of wheat system production or processing inputs (seed, fertilizer, pesticides, machinery) can provide guidance for CAC policymakers and identify opportunities for US agribusiness.

Human and Institutional Capacity Development

- Working linkages are in place among agricultural researchers, educators and trainers, extension services, farmers' organizations, non-governmental organizations, and private sector agribusinesses.
- US and CAC graduate students are trained through coursework and research and exposed to international issues and professional networks.
- US researchers access and use literature and results of relevant research in CAC and the former Soviet Union and the International Agricultural Research Centers.
- CAC scientists access the same resources from the US, CIMMYT, International Agricultural Research Centers and others.
- Partners have access to increased funding for research from US, international and local CAC sources.

The experience of the US Land Grant Universities and the US competitive research grants programs brings a unique system and approach that is beneficial for the CAC. The scope of the project remains broad, both geographically and thematically, but the resources are limited. With time the project will evolve towards more specifically defined areas where the US-CAC collaboration will be most advantageous for both partners.

THE FUTURE CHALLENGE

Despite the significant scientific expertise in the research institutions of the republics of the former Soviet Union (in the Academies of Agriculture, Academies of Science, Universities, and Ministries of Agriculture), this potential has not been effectively mobilized in support of agricultural development. Institutions have lacked the funds to maintain facilities and equipment and to operate programs. In addition, the traditional programs in agriculture and many other sectors are lacking funding and are not always able to meet evolving needs. As the CAC countries adjust to a new marketplace, strengthened research and educational capacity as well as new forms of governance and heightened awareness of the importance of the natural resource base will be required. With these functions and their delivery infrastructures in a state of near collapse in all eight countries, this grant will model a new paradigm for CAC research to support sector development and reform.

Interest in the project has been exceptionally high throughout all the CAC countries, and is growing. They have all actively participated in the planning and management organization of the project as well as in the initial collaborative research efforts. The project has found that following the events of 11 September 2001, International and US attention on Central Asia and its neighbors are at unprecedented levels. CAC countries such as Uzbekistan and Tajikistan have served as invaluable allies in the regional fight against terrorists. Yet the economies and political systems in the CAC region itself are fragile. The proposed research partnerships will contribute to enhanced food security, preserve threatened biodiversity, support democratic and market reforms, and develop mutual understanding and appreciation among our institutions, citizens and nations. It is truly a “win-win” scenario for all of us.

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APPENDIX

Book Review and Central Asian Maps

**“Rangelands of the Arid and Semi-arid Zones of Uzbekistan. 2003.”
(426 p. Euro 76.00)**

**Gustave Gintzburger, K. N. Toderich, B. K. Mardonov, and M. M.
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Reviewed by: Journal of Range Management

Rapidly escalating international interest in the rangelands of Central Asia is manifested in the new book, “*Rangelands of the Arid and Semi-arid Zones of Uzbekistan*”, a joint publication of CIRAD and ICARDA, by G. Gintzburger, K. N. Toderich, B. K. Mardonov, and M. M. Mahmudov. It is a broad, introductory survey of the rangeland ecosystems, and range-livestock systems, and pastoral culture of the region. The book draws on the collective work of many international researchers that have been active in the area over recent decades, including the work of Russian-speaking scientists, much of which has been inaccessible to Western scientists.

The content of “*Rangelands of the Arid and Semi-arid Zones of Uzbekistan*” essentially consists of 7 parts. Following a brief introduction, Part 1 examines aspects of the environment of the region, including geological, climatological, edaphic, phytogeographic, and agricultural fundamentals of the zones.

The book contains notably detailed descriptions of the region's bioclimatology, including some informative, statistical figures showing climatological relationships. Although the book has significant emphasis on grazing throughout, it contains surprisingly few data or estimates of forage production, especially considering the depth of the bioclimatological content. **This first section** does contain some descriptions and data of trends in livestock numbers and agricultural land use. **The second principal section** of the book is a description of the flora and of the main vegetation types of the region. This section includes a number of detailed tables of data on the soils, flora, and especially, the climate of the area. Forage production data, and forage supply/demand information are again limited.

Some of the tables in this section are sufficiently detailed that they might have been moved to an appendix, but they are uniformly well designed.

Section 3, involving the descriptions of individual plants, is the largest section of the book. The plant species are arranged alphabetically by family name. Many of the plant names are familiar here, which will remind North America range management scientists of the rich history of plant introductions from Central Asia. The plant descriptions are informative, and include individual subsections describing characteristics of morphology, reproduction, pastoral importance, fodder value, economic interest, habitat, and distribution. Each species description contains from 1 to 4 color photographs of the plant or its parts. Monthly production tables are provided for a few species for which such data are available.

Section 4, on the ecology, biology and economic importance of arid and semi-arid range plants briefly surveys a range of subjects, including floral life forms, chemical composition of plants, toxic and medicinal plants, plants that cause mechanical injury, seed characteristics and germination ecology.

The book's **fifth main section**, on rangeland improvement and rehabilitation in Uzbekistan, includes 17 pages of text and tables on the history of, and the prospects and botanical options for, range improvement and rehabilitation. Several tables here include important general information on species characteristics relevant to range improvement.

A **25-page section** describing the nature reserves of Uzbekistan is the next major section. Included here are interesting descriptions and photographs of reserves located in the different ecosystems of Uzbekistan. In the book's final main section, a one-page statement of general conclusions precedes 10 pages of color maps, the book's extensive bibliography, an interesting glossary in English and Cyrillic, appendices of meteorological stations, climatological figures, and phylogenetics of major rangeland plants, a general index, and bios of the authors and acknowledgements of their cooperating organizations.

Any limitations of "*Rangelands of the Arid and Semi-arid Zones of Uzbekistan*" likely reflect more the limited information available on the region than limitations of the authors' efforts. In any case, the book's outstanding features overwhelm any limitations in available regional data that might be manifested in the book.

An exhaustive summary of admirable features would include diverse technical elements of content and format, but more philosophically, the book exemplifies at least three important elements. *First*, the book shows how far range management science has come internationally, not just as an application of ecology, but also as a management science integrally involved with a broader culture. Its excellent photographs are particularly effective in binding together the diverse elements of the book's content into a coherent cultural landscape, and should remind

Westerners (of a couple of kinds) of the diversity of potential environmental, ecological, and cultural content of range management science. Rarely has range management science seemed more coherent.

Second, plenty of information useful in management is included in a thoroughly bioclimatological, ecological, and cultural context, with a refreshingly natural, unapologetic tone characteristic of a part of the world where grazing on a range is not a discouraging word. Grazing seems a natural part of ecology in this book—more natural than it ever does in current American books on ecology or grazing management, or in books from any region where grazing is not naturally accepted as the major element of the prevailing culture. Rarely has range management science seemed more comfortable.

Third, as a result of (1) and (2), the range management science in the book does not seem economically marginalized to irrelevance by pressures of industrialized, specialized agribusiness and eco-business. Range management science is inherently important for the landscape and the culture. Rarely has range management science seemed more relevant.

Rangelands of the “Arid and Semi-Arid Zones of Uzbekistan” will be an indispensable reference for range management scientists and range managers in Central Asia, and parts of it will be fascinating reading for individuals involved with rangeland plants, the bioclimatology of steppe regions, and pastoral societies. It will certainly be a valuable referential base for future regional research. In fact, any individual traveling in the drier parts of Uzbekistan who has more than a superficial interest in the climatology and ecology of the region would find this book extremely valuable as a field guide to plants, vegetation types, and climate.

Readers will find photographs of Dr. Gintzburger and his colleagues accompanying their brief bios near the end of *“Rangelands of the Arid and Semi-Arid Zones of Uzbekistan”*. Their book is a tribute to how attractively range management science can be packaged and presented to both professionals and to the public. A text that keeps moving, insightful photography, efficient, attractive figures, and concise tables are combined with an energizing format to create an aesthetic scientific contribution. Rarely has range management science ever looked better.

David L. Scarnecchia, Washington State University, Pullman.



Fig. 1. Location Map of Central Asia.

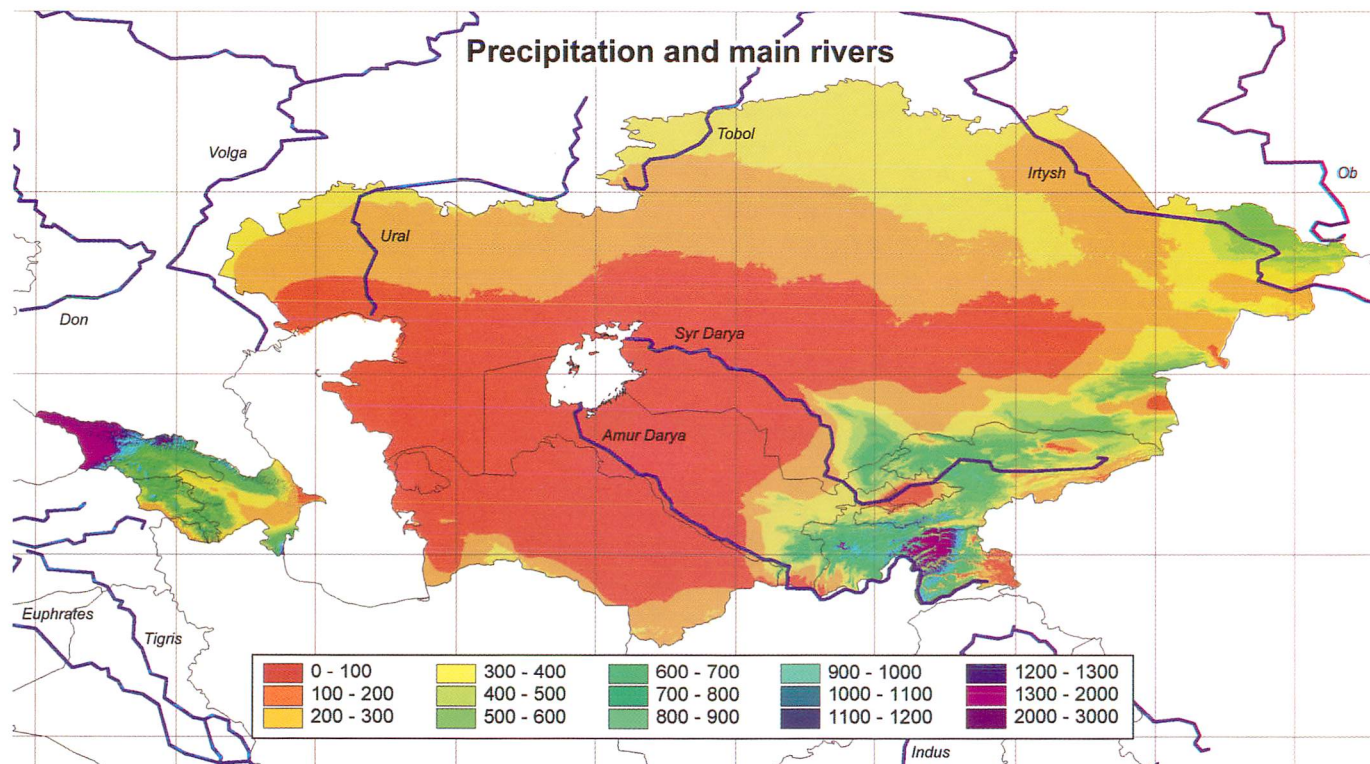


Fig. 2. Precipitation and main rivers of Central Asia.

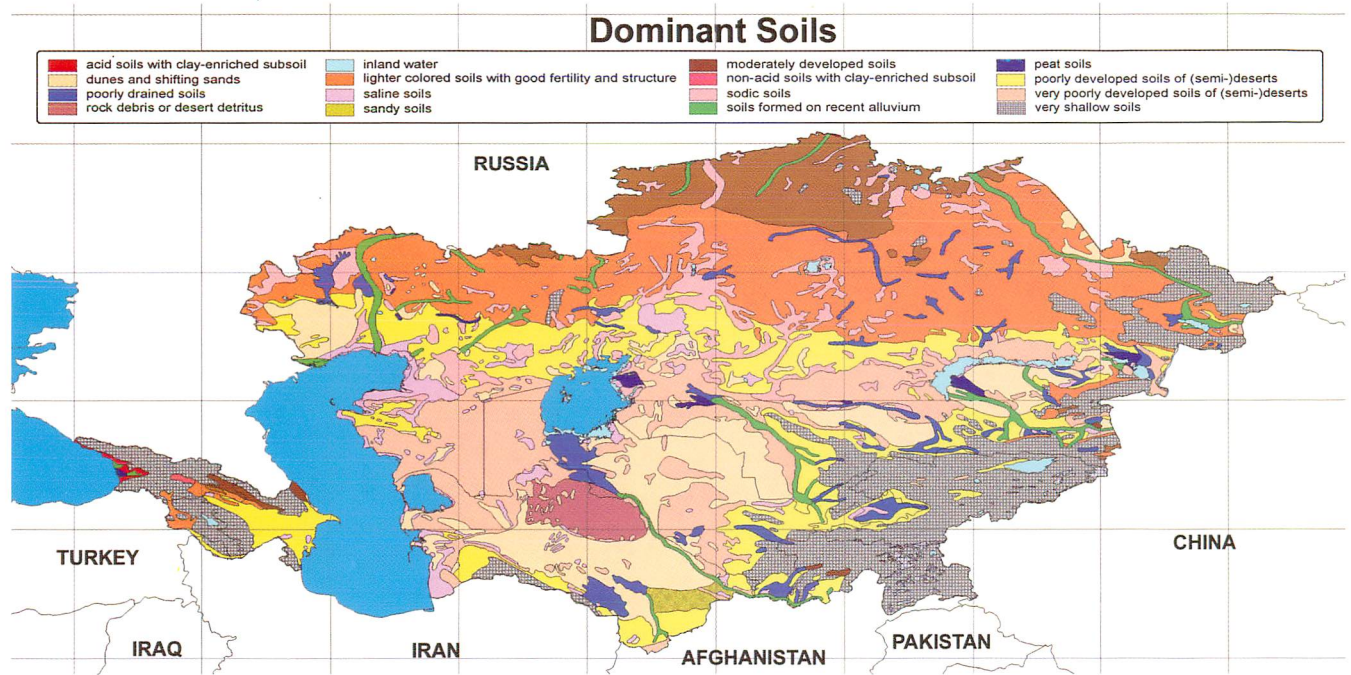


Fig. 3. Dominant Soil types in Central Asia.

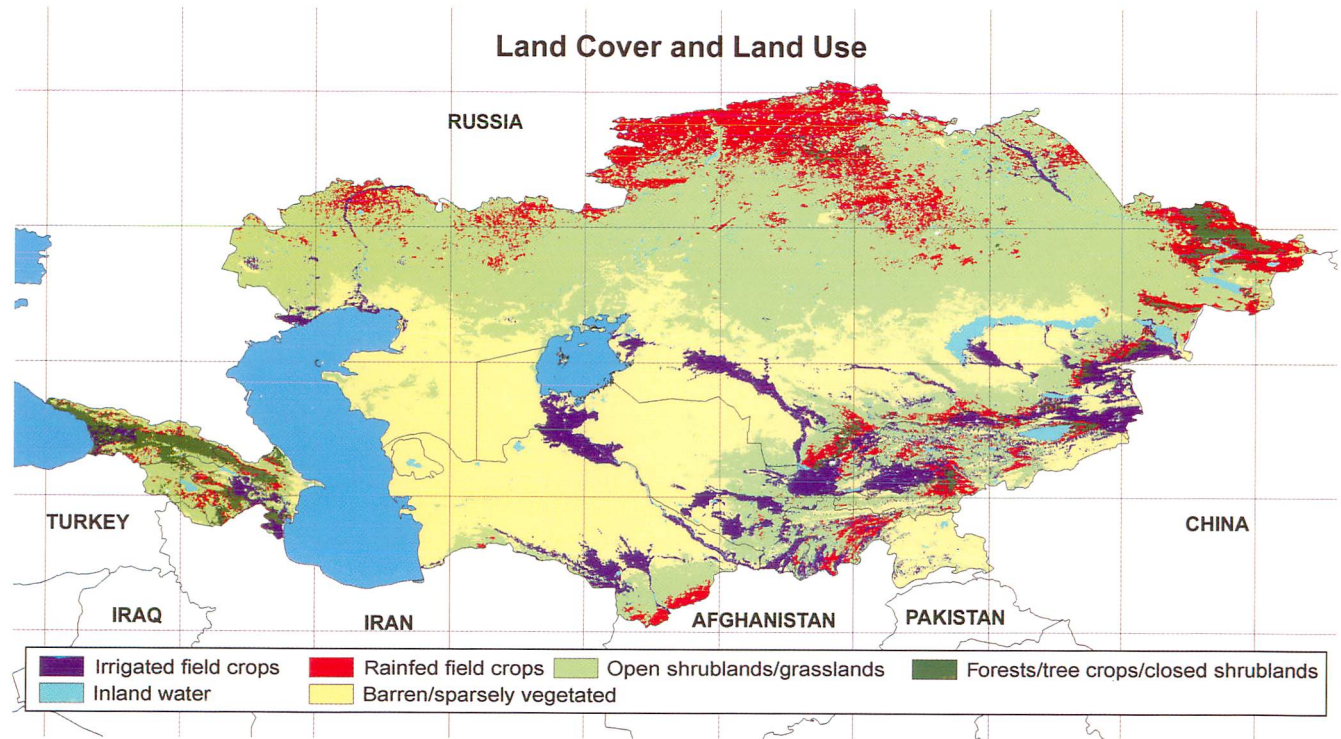


Fig. 4. Land cover and land use in Central Asia.

