CWANA CHAPTER 5

LOOKING FORWARD: ROLE OF AKST IN MEETING DEVELOPMENT AND SUSTAINABILITY GOALS

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Key Messages

1. **Agricultural knowledge, science and technology (AKST) has an essential role in meeting sustainable development goals of reducing hunger, improving human health, reducing poverty, improving livelihoods, and attaining environmental, social and economic sustainability. Furthermore, it may help cope with scarcity of resources and food insecurity, which are major causes of conflicts.** Increased agricultural productivity is a direct driver for reducing hunger and improving nutrition and human health in that sufficient and more nutritious and diverse food results in a healthier constitution and improved body defenses. Increased production may also help increase income, thereby reducing poverty and improving livelihoods of farming populations (economic sustainability). Livestock not only generates income for many poor families in CWANA but also increases their security by serving as “living banks.” Adequate farming practices allow for sustainable and efficient management of natural resources and enhance ecosystem services. AKST may thus reduce pressure on scarce or disputed resources and thereby reduce conflict potential. Holistic approaches in AKST therefore are appropriate for the multifunctional role of agriculture.

2. Agricultural productivity in crop and livestock production and aquaculture may be substantially improved in many areas of CWANA. However, appropriate measures have to be taken that increasing productivity does not compromise sustainability of production with regard to ecological, economic and social aspects. Through intensification of irrigated production, certain countries in CWANA achieve the highest crop yields worldwide. Substantial increases in crop production can come through Increasing soil fertility with organic and inorganic fertilizers, protecting crops against pests and diseases, controlling weeds, developing and using high-yielding species and varieties (derived through both conventional breeding and biotechnology) adapted to site-specific conditions (participatory decentralized breeding) combined with locally adapted mechanization. Integrated crop management practices that include crop rotation, integrated pest management (IPM), regular soil fertility analysis, and use of buffer and compensation areas may reduce negative effects on the environment of such intensification. Increased livestock production in CWANA to meet the rapidly growing demand for meat and milk products will probably have to be based on intensified mixed systems since land degradation due to excessive stocking rates on rangelands is already widespread. However, the potential threats of pollution as well as to animal and human health and welfare will have to be watched cautiously. Removing policy distortions that promote artificial economies of scale (e.g. in livestock production), developing approaches to let poor producers capitalize on the benefits of production, and regulating environmental and public health concerns will represent important challenges for CWANA decision makers.

3. Capitalizing better on the wealth of locally developed and modern technologies for improving the productivity of scarce water resources will allow for substantially higher production or reduced water use in agricultural production, or both. Management factors that increase crop yield generally also increase water productivity. Optimal planting dates, appropriate soil management, mulches, windbreaks and protected production can reduce crop water requirements substantially. In rainfed production, maximizing infiltration of precipitation and reducing runoff, water harvesting, and using drought-tolerant varieties may further increase productivity of scarce water. Supplemental and deficit irrigation may increase water productivity massively. Water losses in irrigation and conveyance systems can be reduced by piping, lining and regularly maintaining the system; optimizing water distribution in the field using appropriate irrigation systems and scheduling irrigation properly can increase field application efficiency. Proper irrigation practices and the assurance of good drainage can avoid salinity. However, even the most sophisticated irrigation scheduling tools are of little value if systems for organizing, allocating and distributing water are deficient, and if the capacity to deal with these systems and the awareness about the importance of saving water are lacking.

4. Integrated water resources management (IWRM) aims to coordinate development and management of water and related resources. Involving all pertinent stakeholders in IWRM allows consideration of water demands in sectors other than agriculture. Major challenges of IWRM in CWANA include developing currently untapped water sources, preserving water quality, managing demand and handling transboundary collaboration. Potential for capturing currently untapped water resources exists through water harvesting, including dams and groundwater recharge, and using unconventional sources such as reclaimed, recycled, brackish, salty, desalinated water and fog collection. Preserving water quality is important for all water users; it may pose particular problems where agricultural productivity is pushed to use more agrochemicals. Managing water demand may include using water efficiently in irrigated agriculture, but also building awareness, handling incentives and disincentives with financial and economic measures such as water pricing, or trading in virtual water. IWRM aims at managing water and related resources efficiently in ways that will maximize the resultant benefits in an equitable manner for different uses in all sectors without compromising the sustainability of ecosystems. Participation in pertinent negotiations of all stakeholders involved helps avoid conflicts over water resources at various scales (watershed, canal, international).

5. The different forms and causes of land degradation in CWANA require specific approaches to reduce and reverse the degradation. Besides developing and disseminating sustainable land management practices that fit specific conditions, socioeconomic

measures are required for widespread adoption of appropriate land management practices. Land degradation in CWANA ranges from nutrient depletion and erosion through waterlogging and salinization to rangeland degradation and loss of productive land to other sectors. Numerous practices and technological options fostering sustainable land management at field, farm and community or watershed level, which are adapted to site-specific conditions, are available from traditional and modern knowledge. However, besides disseminating this information efficiently, a conducive environment must be created for these technologies to be adopted. Long-term land-use rights for owners and leaseholders, risk reduction measures that include safety nets and credit and saving schemes, and profitability of recommended technologies are prerequisites for their adoption. Participatory land-use and land-management planning that organizes access to and use of land and adequate pricing policies and employment opportunities outside agriculture may ease pressure on land and promote the investments required for more sustainable land use. Developing and implementing national action plans under the United Nations Convention to Combat Desertification (UNCCD) will help combat land degradation through coordinated approaches.

6. AKST can capitalize on the rich biodiversity existing in CWANA, but it also has to counteract the threat that agriculture poses to biodiversity. Given the global changes occurring, particularly climate change, the rich biodiversity in CWANA may gain importance in crop and livestock breeding. Furthermore, markets capitalizing on biodiversity as a source of food, herbal remedies and income are gradually emerging. Strategies for conserving biodiversity include different means of in situ and ex situ conservation. Agricultural practices in ecoagriculture such as agroforestry, compensation areas and biodiversity-enhancing landscape elements and adequate land-use planning including the creation and maintenance of protected areas help conserve biodiversity. Establishing and strengthening gene banks may simultaneously allow capitalizing on biodiversity by using genes from wild relatives of crop species and neglected landraces and supporting their conservation. Implementing National Biodiversity Strategy and Action Plans (NBSAPs) developed through the Convention on Biological Diversity (CBD) may facilitate biodiversity conservation as well as making use of this treasure in CWANA.

7. Numerous approaches to mitigate and adapt to climate change are available, but further research is needed to tackle the differing challenges that CWANA subregions will face. Conservation agriculture, improved rangeland management and adaptations in rice cultivation as well as improved feeding of ruminants and improved manure management may substantially reduce greenhouse gas emissions and possibly increase carbon sequestration in CWANA. Research regarding adaptation to climate change will need particular focus on pest and disease management (resistance, forecasting and modeling, IPM) and the introduction of adapted crops and varieties. Erosion control, floodwater management and ways to cope with saltwater intrusion will probably have to receive additional attention, and efficient management of scarce water becomes even more important. Developing capacity may be required to successfully face the challenges ahead and may also help in benefiting from the Flexible Mechanisms included in the Kyoto Protocol (e.g. the Clean Development Mechanism).

8. CWANA has great opportunities to strengthen and reorient capacity development. Agricultural education, research and extension will need to reorient the currently technology-focused approach to holistic and integrative systems approaches. Higher consideration of socioeconomic aspects and introduction of participatory approaches, including acknowledging the important role of women in agriculture, are required to respond to the real questions of farmers, markets and consumers, and may strengthen local ownership. Value-chain management and risk reduction are important topics for CWANA to strengthen in AKST. Blending local knowledge with modern science may bring novel technologies and approaches to the fore. Education, research and extension may greatly benefit from modern technologies (GIS, simulation modeling, expert systems, etc.) and from improved knowledge management. Links and collaboration between education, research, extension and farmers as well as the interaction with the private sector may make AKST more efficient and effective. AKST impact monitoring and evaluation allow for continued priority setting and sound strategy development.

9. Information and communication technologies (ICT) will allow capitalizing to a greater extent on the wealth of information and knowledge available for AKST. Besides improving information and knowledge sharing, exchange and dissemination through ICT infrastructure development and Internet connectivity, modern technologies such as geographic information systems (GIS), simulation modeling and expert systems make better use of existing information. Investments in ICT infrastructure and capacity development together with adequate information policies will allow sharing, exchanging and disseminating traditional and modern information and knowledge, thus strengthening links among AKST stakeholders in education, research, extension and production. This may reduce duplication of research activities and enable stakeholders in AKST systems to make use of the latest technologies. Access to up-to-date market information can assist decision making at various levels. Investments in ICT will narrow the digital divide gap between rich and poor people.

10. Improving market organization may help reduce postharvest losses and contribute substantially to poverty alleviation and development in CWANA. Only if market organization in CWANA countries is improved may the stakeholders in agricultural value chains fully capitalize on increased agricultural production. Producers, processors and traders need access to credits, markets (e.g. by closing the gap between rural areas and urban centers) and reliable market information, particularly in view of more diversified and market-oriented production. Appropriate technologies and infrastructure are required for well-functioning value chains. Processing facilities at different levels may substantially reduce postharvest losses, and together with the development of agribusiness provide additional income along the value chain, particularly if diversified production (with more focus on nonstaples) targets newly emerging market opportunities (organic products, supermarkets, etc.). Vertical integration and professional value-chain management facilitate quality and safety management at relevant levels and foster compliance with newly emerging standards.

11. Policy adaptations are necessary to realize technological options and develop the capacity required to achieve sustainable development goals (SDGs) to their full extent. Adaptations to policies focusing on risk reduction, functioning markets and value chains, trade, sustainable natural resource management, and strengthened capacity are particularly important to achieve SDGs. For producers, improved access to credits, loans and insurances, and adequate input and product pricing (considering the possibility of subsidies and direct payments) are particularly important with regard to economic performance. Appropriate policies regulating access to and use of land and water resources, possibly realized through decentralized participatory approaches, may promote investments and adoption of sustainable practices. Adequate import and export policies (including transit procedures) and trade arrangements (based on proactive engagement in trade negotiations) can greatly strengthen the position of CWANA producers and agrobusinesses in globalized markets. Food safety and biosafety guidelines and regulations, legislation for being compliant with and competitive in international trade, regulations and legislation on intellectual property rights (IPR), and liberal information policies stressing access and transparency are framework conditions required for a productive, efficient and competitive agricultural sector. Integrating AKST in national development strategies and plans may reconcile conflicting views and ambitions with regard to national goals such as national security, food sovereignty (trade in virtual water, etc.), economic growth and development, and quality of life.

5.1 Role of AKST in Meeting Sustainable Development Goals

5.1.1 Hunger, nutrition, and human health

Increased agricultural productivity is a direct driver for reducing hunger and improving nutrition and human health in that sufficient and more nutritious and diverse food results in a healthier constitution and improved body defenses (Rosegrant et al., 2005). Increased agricultural productivity also directly helps increase income, thereby reducing poverty and securing livelihoods of farming populations (IFAD, 2002; Rosegrant et al., 2005). Higher productivity may further allow for more diverse food production and thus more diverse and higher-quality diets, which not only provide sufficient protein and vitamins, but also help combat micronutrient deficiencies.

However, increasing productivity has to be approached cautiously; too often a narrow focus on productivity gains results by exploiting natural resources unsustainably through overuse and pollution (environmental degradation), causing problems related to food quality and safety with negative effects on nutrition, health or marketability, or by neglecting social aspects in trade-off with profitability (including abuse and social dumping). Therefore, AKST-related initiatives need to be guided toward sustainable agricultural productivity in achieving development goals.

5.1.1 Poverty and livelihoods

In CWANA an estimated 70% of the poverty is in rural areas, even though only some 43% of the total population lives there (El-Beltagy, 2002). Despite the large dependence of the rural population on agriculture, emphasis on agriculture and rural development is declining. In addition, the region is facing a number of converging trends that threaten the future livelihoods of the poorest sector of society (Thomas et al., 2003).

It is generally agreed today that poverty reduction requires a holistic perspective focusing on understanding root causes, removing constraints, and creating opportunities and choices for improving livelihoods. Sustainable livelihood approaches based on the principle of reducing poverty by empowering the poor to build on their opportunities are today considered more successful than sectoral approaches to development, which focused on resources rather than people (Carney, 2002).

AKST has to play an important role in various aspects: AKST may support farmers in managing assets, reducing vulnerability, and transforming structures and processes. AKST plays a key role in shaping the quality and quantity of and access to natural, human and other resources, as well as the efforts of those working at different levels (household, national, international) to reduce poverty and hunger in a sustainable manner (DFID, 2007). With regard to agricultural production, some studies indicate that a higher crop yield of just 10% may lead to 6–10% reduction in the number of people living below the poverty line (Irz et al., 2001). CWANA can improve crop production considerably through optimizing the use of production inputs such as water, fertilizers, pesticides and proper crop varieties in a sustainable approach. Agricultural education and better training of farmers may also accelerate development and improve livelihoods considerably.

5.1.3 Environmental sustainability

Environmental sustainability may be adversely affected by efforts aimed at increasing agricultural and economic development—efforts important for achieving the first Millennium Development Goal (Rosegrant et al., 2006). The pressure is to modernize and intensify agricultural systems to meet the food demands of an increasing population. It is unlikely that AKST can develop the agricultural sector in CWANA in such a manner that only benefits and no negative externalities accrue. Further expansion of agriculture dependent on inorganic fertilizers, pesticides and machinery applying agricultural practices like tillage, drainage, irrigation, and fertilizer and pesticide application will undoubtedly have their impact on the environment. In the light of this, it is imperative for CWANA countries to undertake, in their planning process for any agricultural development effort, a judicious, comprehensive and participatory assessment of environmental costs and benefits. A productive agricultural sector will reduce pressure on and contribute to ensuring environmental sustainability.

Since water is a major limiting natural resource in CWANA and agriculture is the leading consumptive user of water, AKST plays a key role in satisfying competing demands for this scarce resource and in raising public awareness of the effect agriculture has on the environment (Bonnis and Steenblik, 1998). Besides the focus on quantitative aspects, i.e. on increasing water supply and decreasing water demand, preservation of water quality will have to receive more attention in the future. In this regard, AKST will not only have to concentrate on protecting of water resources against pollution—from agricultural activities as well as from other sources—but will also have to explore ways for using water of lower quality in agriculture. However, AKST will also have to foster the development and adoption of other options that are environmentally sustainable and economically and technically applicable, such as biological control, integrated pest management, integrated crop management, good agricultural practices and organic farming (Clay, 2004).

5.1.3 Economic sustainability

Economics is about using resources efficiently; usually this is expressed in monetary terms. In this sense, the theories regarding sustainable use of resources can be applied to economic sustainability, except that, in monetary terms, one resource can generally substitute for another

(University of Reading, 2005). Economic sustainability is usually associated with the ability to maintain a given level of income and expenditure over time. Maintaining a given level of expenditure necessarily requires that the income or revenue that supports that expenditure also be sustainable over time. In the context of livelihoods of the poor, economic sustainability is achieved if a minimum level of economic welfare can be achieved and sustained (DFID, 2001).

With regard to agriculture, economic sustainability relates to the long-term ability of farmers to obtain inputs and manage resources. At the level of the individual farm this means that a farm business must remain financially viable while providing an acceptable livelihood for the farm family (Lien et al., 2007). Economic sustainability of a farm is therefore subject to the viability of, and markets for, an enterprise or product. Economic sustainability of an agricultural sector is subject to the whole economy—locally, nationally and internationally (University of Reading, 2005).

AKST therefore plays a crucial role with regard to economic sustainability of agricultural production. AKST can help in using resources and assets efficiently by developing appropriate technologies and practices that may reduce labor requirements. It can facilitate access to viable markets and lobby for adequate input and output prices. It can support the development of well-functioning saving and credit systems that allow for making necessary investments in agricultural production and value chains. Thus, AKST's role with regard to economic sustainability of agriculture has to focus on different levels, from field and farm up to the policy level.

5.1.4 Social sustainability

Social sustainability requires that the cohesion of society and its ability to work towards common goals be maintained. Individual needs, such as those for health and well-being, nutrition, shelter, education and cultural expression should be met (Gilbert et al., 1996). Social sustainability is therefore dependent on a particular set of social relations and institutions, which can be maintained or adapted over time (DFID, 2001).

For a socially sustainable community to function and meet the basic needs of its members, it must be able to maintain and build on its own resources and have the resiliency to prevent or address problems in the future. The community has two types or levels of resources available for building social sustainability:

- Individual or human capacity refers to the attributes and resources that individuals can contribute to their own well-being and to the well-being of the community as a whole. Such resources include education, skills, health, social values and leadership.

- Social or community capacity is defined as the relationships, networks and norms that facilitate collective action taken to improve upon quality of life and to ensure that such improvements are sustainable (Gate and Lee, 2005).

The role of AKST lies particularly in attaining social sustainability in rural communities. On one hand, AKST can foster social sustainability by improving farmers' capacity for enhancing their own well-being and, in accord with their environment, the well-being of communities through increasing their skills to achieve sustainable production and improved livelihoods. On the other hand, AKST can promote networks involving rural populations that facilitate achieving sustainable development. Contributing to more equity (e.g. regarding access to resources and key services) and participating within the society may represent a further task of AKST with regard to achieving social sustainability. By facilitating sustainable development in rural areas AKST contributes to reducing population growth rates, to decreasing differences between rich and poor and between genders, and possibly to reducing migration from rural areas to urban centers, which may further help in attaining social sustainability.

5.2 AKST Options to Overcome the Challenges in CWANA

5.2.1 Technological options

Agricultural growth and increased farm productivity create wealth, reduce poverty and hunger, and may protect the environment, particularly in developing countries (CGIAR, 2006). Since crop and livestock productivity is generally low in rainfed production systems of CWANA, technologies facilitating increased agricultural productivity remain an important pillar toward achieving the development and sustainability goals of the region.

Crop production. Apart from the general management strategies and practices commonly applied to increase crop productivity, management strategies and practices to use water efficiently and productively are of utmost importance in the dry areas of CWANA. As a rule, any management factor that increases crop yield also increases water productivity because evapotranspiration generally increases less than yield production (Turner, 1986). Adequate soil fertility and fertilization, crop protection against pests and diseases (which reduce productivity and increase water use) and weed control (weeds compete for water, nutrients, light) therefore not only increase crop production but also increase the efficiency of water use.

Similarly, high-yielding species and varieties (developed possibly through hybridization, apomixis, or possibly genetic engineering) adapted to the specific conditions of a certain location (through participatory decentralized crop-breeding programs) may use water more productively if managed adequately than varieties or landraces with inferior yield potential.

The choice of optimal planting date can, in combination with short-duration varieties within suitable crop rotations, increase water productivity substantially by making the best possible use of limited precipitation and by moving the cropping season into a period of low evaporative demand (“seasonal shifting”; see van Duivenbooden et al., 2000). Improved meteorological forecasting and supplemental irrigation, possibly combined with mechanization, may greatly facilitate moving the cropping season for better water-use efficiency.

Appropriate crop rotations or relay and intercropping practices, including food legumes that fix atmospheric nitrogen, also make better use of limited precipitation; growing a legume crop instead of fallowing every second year has proved to increase water productivity substantially in cereal production in West Asia and North Africa (WANA) (van Duivenbooden et al., 2000). In addition, crop rotations may reduce weed, pest and disease pressure and positively influence soil fertility and structure.

Mulches of crop residues combined with appropriate soil management may not only reduce unproductive evaporative water loss from the soil surface but also enhance infiltration of scarce precipitation. Mulches may thus reduce wind erosion, soil temperature and surface sealing, and contribute to improved water productivity if their effect on soil temperature does not prolong the crop growing period into a dry season. A large soil volume that crop roots can explore is crucial for storing water for crops to use. Therefore, management factors that increase soil depth and give roots access to soil volume are important for making optimal use of scarce water. Such factors include breaking impermeable layers, building terraces and other structures to mitigate erosion, fertilizing for vigorous root growth and increasing soil water-holding capacity. Particularly in windy areas windbreaks may reduce evapotranspiration through an ameliorated microclimate and thus improve water-use efficiency provided that competition of the windbreak species (usually trees) does not limit crop production. Other options such as dense canopies, ground cover, shade, plastic tunnels and greenhouses can reduce evapotranspiration and increase the relative humidity of the ambient atmosphere, greatly increasing water-use efficiency.

In many cases, such as mulching or adequate soil management, some degree of mechanization may greatly support management practices fostering a more efficient use of limited water resources and precipitation. Furthermore, profitable markets and access to them are a general prerequisite that strategies and practices for increasing crop and water productivity can be implemented (profitability of investments required). Often access to credit at a reasonable interest rate is required to ensure that necessary investments can be profitably made.

Rainfed cropping. In addition to the above-listed general strategies and practices to increase crop and water productivity, certain management aspects are of particular importance in rainfed cropping. To store as much water as possible in the soil, maximizing infiltration of precipitation and reducing runoff is a major priority for improving the water supply to crops in environments where water is a limiting factor for plant growth.

Water-harvesting technologies of collecting, storing and concentrating precipitation at micro, meso and macro scale may not only increase crop productivity in dry areas but make it possible to produce crops in environments where cropping would not be possible without such technologies, because they minimize the risk of crop failure. Additionally, water harvesting may protect land from degradation and desertification (see 5.2.1.2.1). Developing and using drought-tolerant or drought-resistant plant material with high yield potential is prerequisite in the drought-prone areas of CWANA if irrigation is not available or feasible. Recent evidence shows that prospects for improving yields and water productivity in rainfed agriculture are considerably more promising than previously assumed (Rosegrant and Cai, 2000; Rosegrant et al., 2002b; Comprehensive Assessment of Water Management in Agriculture, 2007 vs. Seckler and Amarasinghe, 2000). A change in breeding strategy to directly target rainfed areas rather than relying on “spill-in” from breeding for irrigated areas seems key to this development (Rosegrant et al., 2002b).

However, also policy changes, such as providing a policy environment that does not discriminate against rainfed areas, and infrastructure investment in these areas, such as access to input and output markets, are required to increase productivity in rainfed cropping. Decision-making power will have to be increasingly delegated to communities and social groups and in particular women, who actually manage the natural resources and depend on their sound management for their livelihoods. Key strategies to follow for sustainable development thus include sustaining investments in agricultural research and extension; improving coordination among farmers, NGOs and public institutions; ensuring equitable and secure access to natural resources; empowering land users for effective risk management; and increasing investment in rural infrastructure (Rosegrant et al., 2002b).

Irrigated cropping. In addition to the management factors discussed above, irrigation-specific options may be considered to render irrigated cropping more water efficient and productive. Irrigation and conveyance systems should be planned and improved to minimize water loss. Piping, lining and regularly maintaining conveyance systems are ways to reduce water loss through evaporation, percolation at the bottom of canals, seepage, overtopping, bund breaks, leakage through rat holes and runoff (Brouwer et al., 1989). Optimizing water distribution in the field is key for efficient water use in irrigation (University of Arizona, 1999). Field application efficiency may be increased by improving irrigation systems and scheduling irrigation efficiently (Solomon, 1988; Allen et al., 1998). Particular attention should be paid to exploiting the potential of supplemental and deficit irrigation, which may increase water productivity tremendously (figure 5.1) and greatly reduce the threat of crop failure (risk reduction, stability) (Oweis et al., 1999). In Syria, for example, spreading a given amount of limited irrigation water supplementing precipitation on a larger area, hereby not fully satisfying crop water requirements, allows achieving considerably the higher total crop yields and water productivity as compared to using the water for full irrigation on a smaller area (Oweis and Hachum, 2001).

[INSERT FIGURE 5.1]

In some of the richer countries of CWANA, high-tech irrigation systems may be used to reduce water use for irrigation; however, low-cost irrigation systems are in general of greater need in the region. Besides improving the performance of gravity irrigation systems, such as basin, border or furrow irrigation, and low-cost sprinkler systems, in particular portable hand-move systems, great potential exists for low-cost micro-irrigation systems (SIMINetwork, 2006). However, proper irrigation practices (see Aillery and Gollehon, 2003) are prerequisite for efficient water use with any irrigation system; practices worked out in developed countries such as the United States may well be suited or adapted to conditions prevailing in the water-scarce environments of CWANA. Modern tools for improved irrigation scheduling such as crop simulation models fed with actual climatic data and coupled with GIS can greatly improve water productivity and help manage water resources for irrigation even at large scale, such as in the Jordan Valley or Egypt.

It is important to raise awareness that by using less water more efficiently high yields of good quality are achievable. Education and training are extremely important to raise understanding of how much water a crop requires and how water may be managed more efficiently, avoiding the negative effects of over irrigation. Socioeconomic factors such as awareness and experience, but also the financial capacity of the farmer, access to affordable inputs and knowledge regarding irrigation systems and their maintenance and scheduling are "soft" factors that are as important for productive water use in irrigated cropping as technological aspects.

However, even the most sophisticated irrigation and scheduling practices are of little value if water organization, allocation and distribution systems are deficient. In many CWANA countries water is allocated through public entities. Several excellent examples of water allocation systems, such as in the Jordan Valley, may show the way toward managing water more productively at the project or perimeter level. Establishing water user associations that jointly organize and manage water allocation and distribution may represent another way to facilitate productive water use considerably and at the same time empower local populations while relieving public institutions.

Salinity represents a major threat to irrigated agriculture in most areas of CWANA because evapotranspiration generally exceeds precipitation to a great extent—as early as in the third millennium BC, the Sumerian cities of Mesopotamia crumbled, partly because of salinization due to poorly managed irrigation. Proper irrigation management and availability and maintenance of suitable drainage systems are keys to avoiding land degradation due to salinity. Particularly in cases where unconventional water sources are used for irrigation, such as drainage of brackish water, management practices have to consider the considerable threat of salinity. Strategies and technologies to avoid salinization are sufficiently known.

Rendering water use more efficient in irrigated agriculture is not only important for increasing crop productivity in dry areas (and thus revenues and livelihoods of irrigating farmers; see Lipton et al., 2003). Saving water in agriculture frees up substantial water resources that may be used in other sectors and activities, which is important for overall development of a society. Therefore, IWRM has become a key principle, in particular with regard to irrigated agriculture.

In conclusion, numerous AKST options to use scarce water resources in CWANA more productively and efficiently in irrigated agriculture already exist. It is important to recognize that in addition to technical improvements, organizational and political considerations, plus increased awareness and understanding are key to using water more productively in CWANA agriculture.

5.2.1.1 Livestock

Livestock is an integral part of most traditional production systems in dry areas, as it is in CWANA. Nevertheless, WANA is importing large amounts of meat to keep up with the growing demand for livestock products, because of population growth, increased urbanization and higher incomes. Expansion of livestock production has so far been achieved mostly by increasing the number of animals—an approach that raises concerns about public health and environmental sustainability. Therefore, other options to increase productivity have to be explored to meet the expected increased demand (Delgado et al., 1999).

Livestock production systems are changing in CWANA as they are at a global scale with three linked factors at play: intensification of livestock production (in some places with stronger crop–livestock integration); increased commercialization of livestock production, particularly in peri-urban areas; and the gradual overcoming of animal diseases as a constraint on production (Morton and Matthewman, 1996).

Three major types of farming systems may be distinguished: grazing systems, mixed systems and industrial systems. These systems may be characterized by different stocking rates—grazing systems having the lowest rates and industrial systems the highest. In mixed systems livestock farming is combined with crop farming, where part of the crop or its by-products are used as feed resources (Chapagain and Hoekstra, 2003).

Traditional pastoralism (based mainly on sheep and goats) and to a limited extent mixed farming still exist in CWANA. However, in the grazing and small mixed-farming sectors of the region, little technological change has occurred (Delgado et al., 1999). Pastoralists are being driven into ever more marginal areas as arable terrain gradually expands. But these marginal lands are increasingly coming into focus as reserves of biodiversity, and thus pastoralism is likely to disappear in many regions where it competes with agriculture (Blench, 2000). In ecologically more favorable environments, notably the Nile Valley in Egypt, competitive dairy systems have emerged that use a mixture of domestic and imported feed resources and intermediate labor-intensive technology (Delgado et al., 1999).

Industrial production units, mainly for poultry and dairy, that have emerged based on oil revenues and the resulting economic expansion have state-of-the-art technology but require imported inputs and the domestic production of others, such as forage production for dairy cows. Most of these systems cannot compete with world markets but are maintained through protection as a matter of political choice. This is due to a certain extent to the fact that CWANA, as does most of Asia and sub-Saharan Africa, lacks the capacity to produce substantial amounts of feed grain at competitive prices. Given that many countries in the region cannot expand their crop area, two possibilities remain to increase feed grain availability: intensification of production on existing land resources and importation of feed. Because much of the gain from intensification will probably be used to meet the increasing demand for food crops (and possibly biofuel), many CWANA countries will have to import substantially more feed grains in the future (Delgado et al., 1999).

In the grazing and mixed farming systems in CWANA, productivity gains still seem possible. Animal nutrition can be improved through different technical interventions, such as dry-season supplementation, unconventional feeds or increased use of silvopastoral systems. Making better use of livestock manure may not only be of interest for mixed systems; by fertilizing fodder shrub plantings it may also improve fodder production and help conserve land in grazing systems. Another way of increasing productivity is through animal breeding, by improving local breeds or introducing high-yielding breeds for crossbreeding schemes. However, the latter approach bears the threat of progressively eliminating rare livestock breeds by genetic introgression, representing a corresponding loss of valuable genetic traits and biodiversity (Blench, 2001).

With regard to animal health, the control of serious diseases is becoming increasingly effective through better understanding of epidemiological aspects such as prevalence, risk factors and transmission mechanisms. Treatment is more easily accessible with easy-to-use control agents such as thermostable vaccines, and with the increased effectiveness, safety and ease of application of veterinary products. As farmers gain confidence that diseases can be controlled, reducing economic risk, they are prepared to invest more in animal production (Morton and Matthewman, 1996; Perry et al., 2005). This important fact will considerably increase livestock productivity in both grazing and mixed systems. Aspects of hygiene are important not only with regard to animal health but increasingly also for marketing livestock products, and they will thus receive more attention. However, institutional aspects related to delivering required animal health services in CWANA need to be evaluated in terms of (1) achieving a balance between public and private roles and (2) finding a mutually acceptable balance between regulatory standards to be maintained and the benefits accruing to those who keep livestock.

Preventing degradation and rehabilitating marginal and degraded land are possible with technical options for improved rangeland management: using rotational grazing, corralling to rehabilitate degraded spots, seeding and planting possibly supported by fertilization and water harvesting, practicing agroforestry with fodder shrubs such as *Atriplex* (saltbush), maintaining livestock biodiversity, reducing the number of artificial water points. However, experience to date suggests that technical inputs alone will have only a limited effect on rangeland productivity and conservation. This experience has been particularly so in completely different ecosocial regions such as the more stable environments of high-potential areas in North America, Australia or New Zealand (Sidahmed, 1996; ALAWUC, 2002).

Improving rangeland management to reduce or reverse land degradation in dry areas is a complicated and tricky issue. Most rangelands in CWANA are commonly owned, often by the state, and their profitability is rather limited, which discourages pastoralists from investing in pastures. Furthermore, traditional ways and authority systems regarding their management have been lost to a great extent (Blench, 1998). The traditional wisdom and knowledge of nomads and extensive livestock herders should thus receive more attention. Future research and technology transfer should be based on well-identified demand by the herders and should build on, complement, support or modify this indigenous knowledge (Sidahmed, 1996). Natural resources such as rangelands, forests, water and wildlife are best managed sustainably by local communities, who depend on them for their livelihood and food security, and not by the state or private sector. Thus state control and ownership of natural resources may have to be reconsidered and possibly returned to the local communities where traditional knowledge on sustainable management still persists (ALAWUC, 2002). The role of the public sector should focus on providing an enabling environment for sustainable natural resource and rangeland management, and on monitoring rather than regulating (Seré and Steinfeld, 1996; Nasr, 1999; Ngaido et al., 2002).

Further aspects to be considered in reorienting policy include integrating crops and livestock more strongly by using pastoral outputs in mixed farming effectively, including intensifying the use of work animals; producing niche products from unusual species or breeds, or high-quality, value-added meat and milk products; developing interlocking strategies to link conservation of wild fauna and flora with pastoral production; and expanding ecologically sensitive, low-volume tourism, using pastoralists to provide services (Blench, 2000). Increasing productivity and profitability of grazing systems may finally allow for better management of rangelands. This is important because pastoralism on rangelands can indeed make efficient use of scarce and patchy resources, although its proportional contribution to the overall livestock product market in CWANA is continuously decreasing. Additionally, better rangeland management seems to offer great potential for increased carbon sequestration, particularly through an increase in soil organic matter (IPCC, 2000).

Mixed farming systems should still play an important role in the future, since integrating livestock and crop operations remains the main avenue for sustainable intensification of agriculture in many—particularly the drier—regions of the developing world (Delgado et al., 1999). Integrating crops and livestock has manifold advantages and benefits. Livestock uses land that is not suitable for crop production, provides manure for the crops, and may be used as draft power, which allows a certain extent of mechanization. Integrating fodder crops, particularly leguminous crops, in rotations may further improve crop productivity. Additionally, using rotations, including green manures, and integrating livestock into farming systems widens the range of outputs produced, thus reducing the damaging effect of failure or market collapse of any one crop.

Due to the increasing demand for livestock products, in particular milk and meat around urban centers, mixed and intensive peri-urban farming may become more and more profitable, as examples in East and South Asia demonstrate. However, to profit from this opportunity, farmers require access to sound information on markets and market prices. Increased livestock production in CWANA to meet the rapidly growing demand for meat and milk products will probably have to be based on intensified mixed systems since land degradation due to excessive stocking rates on grazing system rangelands is already widespread in the region. However, the potential threats of pollution (as well as of animal and human health and welfare) will have to be watched cautiously. Major problems to be considered and overcome in intensified systems include the threat of polluting water, soil and air through inappropriate waste management, causing environmental and public health dangers; animal health and animal welfare issues; and zoonotic and epizootic diseases and epidemics; and further human health aspects such as hormones and antibiotics in livestock products, and Creutzfeldt-Jakob disease (BSE—bovine spongiform encephalopathy, commonly known as mad cow disease) due to inadequate control of product safety (Delgado et al., 1999; Guendel, 2002). Important challenges for CWANA decision makers will be to remove policy distortions that promote artificial economies of scale in livestock production, develop approaches to let poor producers capitalize from the benefits of increased livestock production, and form regulations to address environmental and public health concerns.

5.2.1.2 Fisheries and aquaculture

The per capita consumption of fish in CWANA was 7.6 kg $year^{-1}$ in 2004, whereas the world average consumption has increased from 13.1 kg $year^{-1}$ in 1992 to 16.1 kg in 2003 (FAO, 2004). Fish consumption is expected to increase in CWANA. However, many fish stocks are under threat due to high fishing pressure. It will be difficult to expand production from capture fisheries at the current level of exploitation. It is therefore expected that production from capture fisheries will grow only slowly to 2020 (Delgado et al., 2003), even if fish resources are managed carefully.

Sustainable management of fish resources will have to include responsible use of fishing gear, reducing by-catch, and improving processing techniques. Developing infrastructure in fishing communities will allow fishermen to increase the quantity and quality of their fishing. Presently, large quantities of harvested fish are discarded due to wasteful postharvest methods. Education in coastal communities is important to introduce new techniques to local fishermen and increase their fishing abilities. This education should also increasingly reach women to increase their participation in fishing activities, particularly in postharvest activities. Having local communities participate in managing fishery resources is important. Local committees, which should include representatives from local fisher communities and government authorities, may facilitate such participation since fishers will participate in decision making in managing fish stocks.

Cooperation is needed among countries to provide more fish food for people and to alleviate poverty in coastal communities. This cooperation should include joint research and the exchange of information and data. More research should be directed toward substituting animal protein in the feed with non-animal protein sources; this will reduce the pressure on important fish stocks that are normally used for fish meal. International and regional organizations should also play their roles in providing assistance to the countries in this field. Such assistance may include financial funding, training local people, conducting research, and giving support for local fishery organizations. More research is particularly needed with regard to biological and economical aspects of fish stocks, to determine the optimum yields of these stocks and to ensure the suitability of production from certain fish species.

In conclusion, the following measures are important to sustainably manage fish resources:

- Provide more information about fish stocks—important for management. This information may include, but is not restricted to, size, structure and other biological parameters of the stocks.
- Develop a plan for sustainably managing fish stocks that allows their responsible use and rebuilding of depleted stocks.
- Develop infrastructure in fishery communities.
- Improve fishing techniques and reduce the amount of by-catch.
- Educate local people in new techniques on fishing and quality assurance.
- Increase the participation of women in postharvest activities.
- Increase the cooperation between countries and international organizations.

Aquaculture. It is expected that aquaculture will grow significantly in some CWANA countries since the growing demand for fish will probably be met mostly through increased production from aquaculture. This growth will differ from one aquaculture sector to another (marine aquaculture, aquaculture in integrated agriculture, production of nonfood fish). Production may be increased either by expanding the cultivated area or by improving the production per unit area (Delgado et al., 2003). The increasing demand for fish, increasing domestic food supply and increasing export revenue are the main forces that will direct the expected growth of the aquaculture industry in the future. Many CWANA countries realize the importance of aquaculture as a valuable food source and an important source of employment, providing a development opportunity for rural communities. They will incorporate it in their development plans.

In poorer communities, small-scale integrated aquaculture can benefit local people and ensure food security. Growing fish along with agricultural crops can use scarce water in fish ponds for crop irrigation. In areas with saline groundwater that cannot be used for agriculture, fish species such as tilapia may be grown to increase the income of local farmers as well as to provide valuable food.

Challenges facing aquaculture differ from one country to another in CWANA, but in general they include limited availability of sites suitable for new aquaculture activities, uncertain provision of a continuous supply of fingerlings, limited availability of local species for aquaculture, risk of disease, and unreliable markets. In some cases, conflicting interests from different stakeholders, such as tourism, agriculture or other coastal uses, will have to be mediated to get access to and use suitable sites; this may often require collaboration between different authorities. In other cases suitable technologies for particular sites will have to be developed as some sites require special technology.

Constraints to developing aquaculture related to land, water and inputs may be faced through adapted technologies such as selective breeding, better health management, water control and modification of feed input (Delgado et al., 2003). However, more research regarding the sustainability of aquaculture production is certainly required; joint development and transfer of technologies between countries may speed up success. Improved harvesting and processing techniques will increase output of high-quality products. Biotechnology in aquaculture may improve production, but it will be important to use such new technologies in a sustainable manner, regulated through proper legislation and monitoring.

Using local fish species is important for sustainable aquaculture as many problems are associated with using exotic species, principally disease transmission. Therefore, research should focus on determining suitable local species for aquaculture. They should have a high growth rate, be resistant to environmental changes and diseases, and be in demand in the marketplace. If an exotic species is to be used for any reason, special procedures should be followed such as a detailed risk assessment of the effect of introducing this species on the local environment and local species, and rigorous quarantine procedures. Some countries do not allow fingerlings of exotic species to be imported, but they allow importation of brooders. This gives the country more surveillance over both the brooders and the hatchlings.

It is essential for CWANA to address environmental issues in developing sustainable aquaculture. Therefore, an environmental impact assessment should be carried out for every commercial project. These projects should promote environmentally sound technologies for managing production. Monitoring is important to study possible negative effects and the best methods to reduce them. Likewise, codes of conduct for best practices and methods in aquaculture should be prepared to ensure sustainability. These codes can be written jointly between the government and the private sector in any country.

Sustainable aquaculture requires effective policies, legal frameworks and institutions. In CWANA, some countries already have policies for developing aquaculture; others are lagging behind. Obstacles to overcome developing a legal framework include conflicting views between different governmental authorities, bureaucratic procedures and inconsistency among the various laws.

Therefore, it is important to encourage cooperation among authorities to use suitable mechanisms to jointly develop a management plan for aquaculture.

5.2.1.3 Forestry

The forested area in CWANA is limited—less than 5% in most countries—but it still harbors great plant biodiversity and offers considerable potential to serve as a carbon sink. Forest ecosystems in these countries are sources of timber, firewood and fiber as well as non-wood forests products in addition to providing many goods and services (IPGRI, 2001). The role of forests is particularly essential in the dry areas of CWANA with regard to their hydrological function in the ecosystem; under forest cover water infiltration is increased, runoff rates are reduced, and thus water availability may be improved. Furthermore, trees importantly protect land from degradation and desertification by preventing wind and water erosion.

Land degradation poses a major threat to sustainable forest development. Countries in CWANA region, therefore, need to adopt more holistic approaches that are compatible with policy reform, technical guidelines and support systems to address rehabilitation and restoration through forest management and planted forest development. In many of these countries, the current rate of industrial development of planted forests barely keeps pace with losses from deforestation and the transfer of natural forests to protected status. It is possible not only to sustain but also to increase productivity in successive rotations of planted forests. This requires a clear definition of sound management of planted forests and their end use. It is necessary to integrate strategies for appropriate silviculture, tree improvement programs and nursery practices, matching species and provenance to sites, and to forest protection and harvesting practices.

AKST may address forestry priorities in CWANA region that should include forest resources management, rehabilitation and restoration of degraded lands, development of forests lands and access to information technology and networks on forestry, and inclusion of forestry and forestry-related issues (IPGRI, 2001). Expanding forests and increasing their productivity may be achieved by using appropriate species, protecting forests from grazing practicing, zoning, practicing water harvesting and using unconventional water resources such as brackish water and treated wastewater for supplementary irrigation of forests in dry areas or seasons.

Agroforestry. Agroforestry systems are generally less widespread in dry areas than in humid environments in the tropics. This is mainly due to the role that competition between crops and trees plays, which is more important in dry than in humid areas. This competition requires cautious reflection on whether and how woody species may be combined with crops and livestock (see Kessler and Breman, 1991; Breman and Kessler, 1995). But agroforestry may provide extremely important products and services in dry areas (Table 5.1).

[INSERT Table 5.1]

It is important to keep in mind that the drylands environment is quite different from environments where many well-known agroforestry practices such as alley cropping have developed. Innovative thinking is required to develop new approaches for using woody perennials together with crops and livestock, and certainly for adapting known technologies to the specific conditions. A participatory approach considering the needs and perceptions of all involved stakeholders is indispensable. Innovation, adaptation and participation will have to receive high priority in AKST with regard to agroforestry in CWANA.

5.2.1.4 Mechanization and labor organization in agricultural production

Adequate, locally adapted mechanization may substantially increase agricultural productivity, particularly in the case of field crops. Furthermore, a certain degree of mechanization may greatly support approaches and technologies to use scarce water resources more efficiently. Conservation agriculture practices such as conservation tillage, which help conserve soil productivity and biodiversity, often require some degree of mechanization. Conservation agriculture technologies will probably become more important in the future since they play an important role in adapting to climatic change and they substantially reduce greenhouse gas emissions. In addition, increasing labor constraints, particularly due to the increasing opportunity costs of labor, insufficient remuneration for agricultural work and the feminization of agriculture, further drive the need for mechanization.

However, mechanization has to be adapted to the specific agroecological and socioeconomic conditions of the farm enterprises. Since production systems and resource availability for farmers in CWANA differ greatly, strategies to improve mechanization must be specifically targeted. Whereas in certain areas, such as those that are resource poor or mountainous, improved crop–livestock integration may allow for simple mechanization through draft power, high-tech mechanization may be adequate in other parts of CWANA. The special case of Central Asia, where the degree of mechanization has considerably decreased since the collapse of the Soviet Union, clearly illustrates this need for specific approaches and strategies. Thus careful consideration of the specific conditions and cost-benefit analyses are necessary to choose adequate mechanization levels. Furthermore, changes in traditions or legal framework conditions may be required to introduce mechanization. For instance, land fragmentation limits increase in productivity through mechanization, and access to reasonably functioning credit and saving systems may be required for farmers to invest in the necessary equipment.

Future AKST relating to mechanization will have to consider changes in labor organization to a greater extent. Hitherto achievements in mechanization have generally unilaterally favored male workers; future efforts will have to focus much more on facilitating and easing the labor-intensive and tedious work of women and children. Awareness building and advocacy will be required to alter social preconceptions that associate machinery use with men and thus further limit women's use of technological improvements. This is particularly important in view of the increasing feminization of agriculture in many parts of the CWANA region, and it must allow for adequate and gender-balanced schooling and education.

5.2.1.5 Alternatives to conventional farming

Production of safe food remains a worldwide health concern. Agricultural chemicals like fertilizers, pesticides and fungicides are a prime food safety concern today. Jones et al. (2006) reports an increased risk of contamination with harmful microorganisms through irrigation water, spraying, cleaning, etc.

Such concerns have led to an increasing interest in developing and adopting alternative agricultural approaches to reduce the use of chemical pesticides and fertilizers. Integrated crop management—which includes integrated pest management—is an option to be considered in CWANA in the future, as is organic farming. Due to changes in consumer habits and perceptions, markets for sustainably produced and organically grown merchandise are growing, and they may represent an opportunity for quite a number of farmers in the CWANA region.

Integrated crop management (ICM) may be seen as a common-sense approach to farming. It combines the best of traditional methods with appropriate modern technology, balancing the economic production of crops with positive environmental management (BASIS/LEAF, 2004). Integrated production farming systems integrate natural resources and regulation mechanisms into farming activities to achieve maximum replacement of off-farm inputs and to secure sustainable production of high-quality food and other products through ecologically preferred and safe technologies. ICM focuses eliminating or reducing sources of present environmental pollution generated by agriculture and sustaining the multiple functions of agriculture while sustaining farm income (EU, 2002); therefore, research for and promotion of ICM systems may be of particular importance in CWANA countries where AKST is focusing on increasing productivity by intensifying production. Although yields currently tend to be a little lower in ICM as compared with conventional systems, a recent study (EU, 2002) suggests that, even in the highly productive agricultural systems in the European Union, it is possible to achieve similar levels of profitability using ICM techniques because lower revenues are balanced by reductions in production costs. Opportunities to achieve comparable or even increased profitability in less productive systems of CWANA are therefore considerable.

Integrated pest management (IPM) forms part of ICM and can be described as an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. Emphasis of IPM is on control, not eradication. The approach thus aims at keeping pests at acceptable levels (identified thresholds) by applying preventive cultural practices, identifying and monitoring pests, and applying mechanical, biological and (as a last resort) chemical controls when required. Since IPM programs use comprehensive information on the life cycles of pests and their interaction with the environment, research might be required to better adapt IPM strategies to CWANA conditions. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means (which is particularly important for resource-poor CWANA farmers), and with the least possible hazard to people, property and the environment (EPA, 2007). Although IPM's main focus is usually insect pests, IPM approaches may encompass diseases, weeds and any other naturally occurring biological crop threat.

Whereas ICM strategies still allow the use of agrochemicals, *organic agriculture* describes production systems that rely on ecosystem management rather than external agricultural inputs. Since organic agriculture renounces the use of synthetic inputs such as synthetic fertilizers and pesticides, veterinary drugs, genetically modified seeds and breeds, preservatives, additives and irradiation, it offers a production pathway that may be particularly attractive for resource-poor farmers in CWANA. In many developing countries, organic agriculture is adopted as a method to improve household food security or to achieve a reduction of input costs. Produce is not necessarily sold on the market or may be sold without a price distinction as it is not certified. Demand for organic products, however, is increasing not only in industrialized countries but—with increasing living standards—also in and around the CWANA region. Market opportunities for organic products are thus on the rise, both in view of exports and to satisfy inland demand; typically, organic exports are sold 20–25% higher than identical products produced on non-organic farms (Abou-Hadid et al., 2004). Vertical integration of market chains has proven to greatly benefit organic producers; small farmers may develop direct channels to deliver uncertified organic produce to consumers or organize themselves to have increased marketing strength in national and international markets.

Evidence is increasing that the transition to more ecological production practices does not compromise food security (IFOAM, 2007). Where external inputs have been high, yield reductions may occur during and after transition to organic farming, but organic agriculture may substantially increase yields in low-input areas (Pretty et al., 2006). In traditional rainfed systems, widespread in CWANA, organic agriculture has been demonstrated to outperform conventional agricultural systems under environmental stress conditions (FAO, 2007). Organic production additionally contributes to conserving biodiversity and natural resources, it may increase income or reduce costs, it produces safe and varied food, and it is sustainable in the long term. Therefore, organic agriculture should be an integral part of any agricultural policy aiming for food security and improved livelihoods (IFOAM, 2007). Organic farmers usually grow a variety of crops and rear livestock; this increases resilience of organic systems and may reduce production as well as market risks.

Whereas the use of genetically modified organisms (GMOs) within organic systems is not permitted during any stage of organic food production, processing or handling, modern *biotechnology*, if appropriately developed, could offer new and broad potential for contributing to food security. Biotechnologies developed over the last 30 to 40 years—such as tissue cultures, cell isolation, molecular diagnostics, marker-assisted selection and genetic engineering—are powerful instruments that can be used for different purposes. Most of these technologies are not controversial and can be used safely to increase food security. Since infrastructure requirements for certain technologies are not overly demanding, some of these technologies may well experience further development in the CWANA region.

An important subset of modern biotechnologies is *genetic engineering,* or the manipulation of an organism's genetic endowment by introducing, rearranging or eliminating specific genes through modern molecular biology techniques. Certain proponents of the GMO community are anticipating a second potential agricultural revolution, the Gene Revolution, in which modern biotechnology enables production of genetically modified crops that may be tailored to address ongoing agricultural problems in specific regions of the world, like developing high-yielding varieties tolerant to salinity and drought, pest and disease resistant. Although the genetically modified crop movement may have the potential to do enormous good, it also presents novel risks and has significant obstacles to overcome before it can truly be considered revolutionary. Evidence so far suggests that the technology has the potential to affect a wide range of plant and animal products and could have many consequences that extend beyond food production in agriculture (FAO, 2001).

Since biotechnology may facilitate increasing agricultural productivity, CWANA AKST should expand research and development efforts related to socially useful and environmentally friendly biotechnologies, including as appropriate the possible development of certain GMOs. However, consideration must be given to the potential benefits for food and nutrition security, and thereby for human health and well-being, on the one hand, and to the need to avoid risks to human health, social justice and the environment, on the other. Adequate safeguards must be put in place to ensure that all concerns are protected, including environmental concerns, while leaving options open for future generations.

Programs designed to bring the benefits of biotechnology to small-scale farmers in the CWANA region should be supported, while seeking to ensure that the aims and the effects of using such technologies serve to reduce hunger and malnutrition. Such programs may also be directed toward enhancing farmers' varieties or landraces that are already well adapted to local growing conditions, thereby adding specific value of interest to farmers.

The most urgent ethical task is to assess activities relating to food and agriculture in the light of their actual and potential impact on reducing poverty, hunger and malnutrition. There is a clear need to balance benefit to human health and the environment with risk. The risks are often unclear, speculative and impossible to test. The benefits of these new crops have not yet been fully demonstrated. People need to feel safe and assured that as far as possible their safety, their health and their beliefs have been taken into account before new forms of food products are introduced.

Although it is undoubtedly a useful exercise to observe the arguments and discussions other countries are having or have had when implementing agricultural biotechnology, it is in the end up to each country, whether industrialized or developing, to assess the benefits and risks as they may affect their own culture and environment, when deciding the best way forward (Kinderlerer and Adcock, 2005). As the potential impact of GMOs to both the environment and health is not entirely understood, many CWANA countries will probably take the precautionary approach and adopt the use of GMOs in farmers' fields only very cautiously. It is uncertain that biotechnology research, particularly related to GMOs, will gain ground in CWANA in the near future, because religious and other social factors may cause people in the region to be hesitant to accept GMO seeds and food crops. Since, however, the possibility exists that farmers start growing GMOs spontaneously, as observed in Pakistan, AKST systems and governments need to develop pertinent regulations and put them in place.

5.2.1.6 Adaptation to and mitigation of global climate change

Adaptation. Since the subregions in CWANA will be affected differently by global climate change, adaptation options will have to be site and situation specific. In many areas of CWANA water is projected to become even scarcer (IPCC, 2007a) and therefore improved *water resource management* and efficient water use will be crucially important. Particularly for rainfed agriculture, technologies such as water harvesting and supplemental irrigation will become particularly important (Pandey et al., 2003). Small-scale irrigation technologies (SIMINetwork, 2006) will gain importance, especially for poor farmers (e.g. for off-season production); access to functioning savings and credit systems will be a prerequisite for small-scale farmers to be able to make the necessary investments. Various water storage options (reservoirs of different sizes, groundwater storage and recharge) will have to be envisaged, particularly in the many areas in CWANA where summer precipitation will decrease (IPCC, 2007a). Investment in hydraulic infrastructure (rehabilitation, maintenance and new establishment) will be required to increase the reliability of water supply under increased water scarcity. Nevertheless, more frequent extreme rainfall events with high intensity will require increased focus on floodwater management, such as the design of dams and other infrastructure for flood protection, and soil surface management to reduce runoff and soil erosion through increased infiltration.

Various options exist to face the increasing threat of *land degradation* and desertification due to reduced vegetative cover as a result of changing climate, increased erosion by heavy rainfall, and climate-induced changes in land use, which leaves soils more vulnerable to degradation. Promoting vegetative soil cover and reducing soil disturbance should be the principle objectives in this regard. Cover crops and green manures, improved fallows and agroforestry practices, conservation tillage and adequate crop residue management will play important roles in protecting land against degradation induced by climate change. Soil and water conservation technologies in general (see Liniger and Critchley, 2007) will certainly gain importance in coping with the adverse effects of climatic changes in CWANA. Conservation agriculture has shown strong resilience to climatic abnormities in Central American highlands according to recent studies (Cherrett, 1999; Holt-Gimenez, 2002). Saltwater intrusion and increased salinity threats may require changes in production systems in certain areas, such as for flooded rice or aquaculture, besides adaptations with regard to species and varieties cultivated. Adaptations in rangeland management will become even more important in view of the predicted climatic changes in CWANA.

Cropping systems management will have to be adapted to changed climatic conditions. Changes may entail introducing new crops and varieties adapted for duration, tolerance and water demand, in crop rotations. Diversifying production portfolios as a strategy to cope with risk might become an important option. Currently underutilized crop species could play an important role in adapting cropping systems and varieties to changed climatic conditions. Introducing new cropping patterns adapted to site-specific conditions will require increased use of modern technologies such as crop simulation modeling and GIS for long-term planning to assess and reduce risks related to changed practices.

Crop breeding will have to focus particularly on improving tolerance to abiotic stress. For rainfed conditions, drought tolerance, early growth vigor for rapid establishment and phonological adaptation to changed climatic conditions are of particular importance. Improving heat tolerance will be a challenge for many crops, such as wheat and rice, to avoid significant yield reductions due to temperatures that will be generally or periodically higher. Since salinity problems will increase with saltwater intrusion and higher evapotranspiration, efforts to increase salinity tolerance of crop species will receive still more attention. Genomic tools might speed up conventional breeding efforts to achieve important breeding objectives. Maintaining biodiversity to exploit genetic diversity in semiarid ecosystems will facilitate adaptation to climate change.

Due to changing climatic conditions producers will have to cope with new and exacerbated *pest, disease and weed problems*. Warmer and more humid winters will lead to insect and pathogen overwintering ranges and their numbers expanding. Increased temperatures are also likely to facilitate expansion of highly damaging weeds such as striga. Integrated pest management will certainly gain importance, and the capacity of research, extension and farmers will have to be strengthened to be able to monitor thresholds, detect signs early, etc. Modeling efforts may need to be strengthened to understand pest–host dynamics under environmental change and to improve predicting how and where epidemics and other increased threats will occur.

Various *crop management practices* will facilitate adaptation to changed climatic conditions. Important aspects to consider include changes in soil preparation such as conservation tillage to improve nutrient and moisture retention and to prevent soil erosion; adaptation of planting and harvest dates or seeding densities; promotion of vigorous crop establishment through adequate soil fertility, addition of fertilizer to seed, seed priming, transplanting, supplemental irrigation; and other adapted management practices such as incremental fertilization.

Livestock production will probably be mainly affected by changes in feed availability because of rangeland and pasture productivity, and grain prices. Whereas intensively managed livestock systems have more potential for adaptation than crop systems, pastoral systems might need more attention since the rate of technology adoption is generally slower because changes in technology are viewed as risky (IPCC, 2007b).

Adaptation options in *coastal areas and marine fisheries* may have to include preventing development in coastal areas vulnerable to erosion, inundation and storm-surge flooding. "Hard" (dikes, levees, seawalls) or "soft" (beach nourishment, dune and wetland restoration, forestation) structures may be used to protect coasts. Storm warning systems and evacuation plans will have to be implemented, wetlands protected and restored, and estuaries and flooding plains maintained to preserve essential habitat for fisheries. Fishery management institutions will have to be modified and strengthened and policies to promote conservation of fisheries revised. Research and monitoring to better support integrated management of fisheries will be required.

However, all technological options to adapt to climatic changes will require an *enabling environment* that includes availability of financial resources, technology transfer, and cultural, educational, managerial, institutional, legal and regulatory practices. Affordability of such measures is, particularly for poor farmers, a prerequisite for their implementation. Access to functional savings and credit systems as well as to input and output markets is important. But also targeted support through adequate pricing policies or payments for ecosystem services will have to be considered to enhance the adaptive capacity of producers, especially in smallholder rainfed production systems and particularly in semiarid areas. Land and water access and use rights will have to be adapted to encourage both men and women farmers to invest in adapted technologies. Access to information, know-how and technology will have to be improved through better links between research, extension and farmers. Proactive risk management strategies will have to replace the currently prevailing reactive disaster management. Besides improved weather forecasting and access to reliable climate and weather information, early-warning networks and support agreements, such as the West African Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel, may have to be developed. Insurance programs for farmers will encourage farmers to invest, improve the social resilience of poor rural populations, and mitigate the risks related to increased climatic variability. Capacity development will certainly be required to successfully face the challenges ahead and may also help in benefiting from the Flexible Mechanisms included in the Kyoto Protocol, such as the Clean Development Mechanism.

Mitigation. Beyond the use of biomass fuels to displace fossil fuels, the management of forests and rangelands and practices in agricultural production can play an important role in reducing current emissions of CO_2, CH_4 and N_2O and in enhancing carbon sinks (IPCC, 2007b). Woody perennials are particularly important in conserving and sequestering substantial amounts of carbon. Therefore, sustaining existing forest cover, slowing deforestation, regenerating natural forests and assisting the natural migration of tree species (e.g. through connecting protected areas and transplanting), establishing tree plantations and promoting agroforestry options are key land-use options for mitigating climate change. Such options as well as reducing conversion of grassland to cultivated land and setting aside ecological compensation areas may be all the more possible if agricultural production is intensified on surfaces less prone to degradation; to this end participatory land-use planning may be required.

Agricultural practices such as conservation tillage, rational management of crop residues (mulching, less burning of biomass) and proper fertilization (improved fertilizer-use efficiency, application matched with demand, incremental fertilization, use of legumes in rotations) may reduce greenhouse gas emissions and increase soil organic matter and thus carbon sequestration. Planting improved fallows and cover crops, improving rangeland management, avoiding soil erosion and particularly rehabilitating degraded lands further contribute to producing and maintaining soil organic matter (Duxbury, 2005; Lal, 2005; IPCC, 2007c).

Methane and N_2O emissions from rearing livestock may be substantially reduced in two ways. (1) Improving manure management, e.g. reducing anaerobic decomposition, may not only lessen emissions but allow for capitalizing on methane production by recovering CH_4 and using it to produce bioenergy. (2) Improving ruminant feeding is another way to reduce greenhouse gas emission from livestock husbandry; processing the feed for better digestibility, supplementing with nutrients and vitamins, or adding probiotics, yeasts and edible oils to animal feed may not only reduce CH_4 emissions but also increase productivity and thus result in a reduction of emissions per unit of product such as meat or milk. Recent experience, as in Australia, provides evidence that CH_4 production by rumen microorganisms may be controlled (Wright et al., 2004).

Methane emissions from paddy rice production may be significantly reduced through adapted water management, e.g. mid-season drainage combined with shallow flooding. Using ammonium sulfate fertilizer, which impedes CH_4 production, and considering new insights in rice CH_4 production in breeding programs may further decrease CH_4 emissions.

Although the strategy of soil carbon sequestration to mitigate climate change has been questioned, the likelihood that CO_2 will revert to the atmosphere because carbon sequestering practices might be abandoned seems rather small. Many of the practices that avoid greenhouse gas emissions and increase carbon sequestration can also improve agricultural efficiency and the economics of production. It is unlikely that farmers would abandon such win-win approaches unless competing demands for natural resources, mainly land, or some larger force compelled them to do so. The discussion however shows that practices to mitigate climate change have to be compatible with sustainable development, that is, they should also meet objectives unrelated to climate such as cost efficiency. AKST might therefore require capacity development in this regard and have to promote reforms of policies that currently encourage inefficient, unsustainable or risky farming, grazing and forestry practices.

5.2.1.7 Market orientation, diversification and risk management

Agrofood marketing, patterns and types of food consumption and food diversity are changing steadily as a result of development and globalization. Food markets are growing five times faster in the emerging market regions of Asia, Latin America, and Central and Eastern Europe than in the United States and Western Europe (Reardon and Flores, 2006). National-level sales are growing at a country average of 7% in upper-middle-income countries like the Republic of Korea, the Czech Republic, Hungary, Poland, Argentina, Brazil, Chile, Mexico, South Africa, and 28% a year in lower-middle-income countries such as China, Bulgaria, Russia, Colombia, most of North Africa and West Asia, compared with about 2% a year in upper-income countries (Regmi and Gelhar, 2005, citing data from www.euromonitor.com). With the expanding agrofood markets, food import bills in many CWANA countries are increasing, and agricultural imports constitute approximately one-fourth of CWANA's total merchandise imports (refer to chapter 1 of this report for geo-economics details).

Another added dimension to market reorientation is the spread of supermarkets and hypermarkets. In Western Europe and the United States, the share of supermarkets went from none in 1920 to about 80% today—65% in Japan. The top four chains in the U.K. now have 50% of the market, chains in Germany 55%, France and Spain 60% (only 35% in the United States) (Cook, 2005). Beside this change in the structure of the food industry globally, there has been a rapid and recent transformation in how food industry firms source farm and processed products from producers. These changes are extremely important for local producers as well as for exporters. Because food industry firms are expanding the coverage of their procurement catchment areas, they are shifting their sourcing from traditional wholesale markets to the "new generation specialized wholesaler". Private standards of quality and safety are rapidly emerging (Reardon and Farina, 2001). This scenario provides an opportunity for AKST to be used to ensure that through enhanced production domestic agrofood products are substituted for imports. AKST can also help add postharvest value in storing, packaging, grading and labeling, by helping suppliers comply with standards and meet sanitary and phytosanitary requirements. It can build technology capital toward supplier upgrading, such as enabling suppliers to meet the tough new private standards like EurepGAP.

The volume of food trade increased 2.1 times from 1980 to 2003 (3.4% annually, faster than the annual rate of growth of GDP/capita in the world of 2.65%). Increases in trade were extremely uneven over product categories, with "nonstaples" the clear winners and grains the clear losers. According to Reardon and Flores (2006), trade in fruits and vegetables grew by 330%; trade in meat, fish and seafood grew 300–400% from 1980 to 2003. Analysis of the production figures for cereals, fruits and vegetables in CWANA region (see 2.1.2.1 for complete statistics on production) make it evident that in CWANA nonstaple crops are of secondary importance to cereals, which are and have long been one of the most important commodities in agricultural production. Due to the traditional and to a large extent nondiversified production trends in the region, CWANA has little exportable surplus of nonstaple crops and hence is not yet able to gain any significant benefit from new marketing opportunities that arise from trade of nontraditional crops.

In food economics, Bennett's Law states that as incomes rise, consumers switch into nonstaples and out of staples (Bennet, 1941). A strong middle class with higher spending power in CWANA is increasingly shifting from traditional to nonstaple food items, resulting in an increase in the food import bill. It is in this context that AKST can be used for agrofood diversification; market opportunities may be captured by producing products that are in high demand. Using AKST to produce nonstaple crops and off-season crops has great potential in CWANA, and it would not only contribute to increased income-earning opportunities for the growers (which in turn would reduce poverty and improve livelihoods) but also to a reduced import bill and rational use of foreign exchange at a macro level. Markets capitalizing on biodiversity as a source of food, herbal remedies and income are gradually emerging (Leaman et al., 1999). CWANA with its huge biodiversity hosts a large number of underutilized crops that might gain momentum in such markets (Giuliani, 2007). In many cases, the potential exists for more widespread use of these species. They include crops that could meet the needs of farmers wanting to increase yield from their land and consumers seeking a more natural and varied diet. They can offer opportunities for farmers to tap different markets and thus represent important new sources of income for rural people. Despite their local and potential importance, these species have been largely neglected by researchers. Information on their agronomic characteristics or nutritional value is often lacking, there is little genetic diversity available in gene banks for breeders to use and the seed industry largely ignores them. Therefore, improving the availability of information on underutilized crops demands more attention. Development of improved processing technologies and market analyses are required to capitalize on such"lost crops". New technologies such as molecular genetics and GIS will certainly play their part in developing conservation and use strategies. Participatory plant breeding approaches as well as marker-assisted breeding may allow obtaining improved plant material.

Diversifying production at various scales, from mixing seeds to integrating crops and livestock, will also substantially reduce production risks, particularly where higher income through sale of high-value products allows for pertinent investments such as small-scale irrigation. Diverse systems are generally more robust and resilient to shock and stresses, and thus better able to cope with risk (Haykazyan and Pretty, 2006; Werners et al., 2007). Crop diversification can considerably reduce the risks associated with pests and diseases, and the risk of crop failures due to such environmental conditions as climatic extremes and changes may be spread over a greater number of commodities. Diversification may also help in financial as well as market risk reduction and can thus contribute to stability, economic sustainability and improved livelihoods. It also allows for more flexibility and opportunities to adapt to changing framework conditions. Risk management strategies at farm level may also include the choice of low-risk activities; although specialty crops such as tomato may offer the possibility of high gross returns they commonly have greater year-to-year production variability than the more common crops (Patrick, 1992).

Because of the multiple sources of risk, comprehensive strategies that integrate several responses to variability are often necessary for effective risk management. In addition to diversification these strategies may include choosing low-risk activities, dispersing production geographically, selecting and diversifying production practices, maintaining flexibility at production level; obtaining market information, spreading sales, practicing forward contracting, participating in government or other programs at marketing level; and insuring against losses, maintaining reserves, placing investments, acquiring assets, and limiting credit and leverage at the level of farm finances. The particular combination of risk-management responses an individual farmer uses will depend on the individual's circumstances, type of risks faced, and attitudes toward risk. Some risk responses act primarily to reduce the chance that an adverse event will occur, while others have the effect of providing protection against adverse consequences should the unfavorable event occur. Farmers find many different ways to implement these principal risk responses (Patrick, 1992). However, for farmers to choose certain framework conditions are prerequisite. These may include access to credit, insurance, markets and market information.

5.2.2 Rational management of natural resources

5.2.2.1 Water

Water management in and for agriculture has to be set in a broader perspective of integrated water resource management (IWRM; see GWP TAC, 2000; for links and resources regarding IWRM see InfoResources, 2003). IWRM aims at the coordinated development and management of water, land and related resources to maximize the resultant benefits in an equitable manner for all sectors and members of society without compromising the sustainability of ecosystems. Thus, IWRM pursues three major objectives: (1) efficiency by maximizing economic and social welfare derived from water resources and investments in providing water services; (2) equity in allocating water resources and services across different economic and social groups; and (3) environmental sustainability by not putting at risk the water system that we depend on for our survival.

IWRM considers water for people—drinking water and sanitation; water for food, i.e. for the farming sector including livestock and fisheries; water for nature—for preserving ecosystems; and water for other uses—industry, recreation, tourism, energy and transportation (SDC, 2005). IWRM therefore necessitates a holistic approach to management, considering the interdependencies within natural systems, but also the way that economic and social systems affect the demands placed on the resource base. It also requires a participatory approach, emphasizing the need for stakeholders to be involved in water development and management (including women as decision makers and water users). And IWRM requires understanding that the demands for water will inevitably outstrip the capacity of the resource base to deliver unless users become aware of the provision costs involved (including environmental costs). IWRM therefore represents a break with tradition, from sectoral to integrated management, from top-down to stakeholder and demand-responsive approaches, from supply to demand management, from command and control to more cooperative or distributive forms of governance, from closed expert-driven management organizations to more open, transparent and communicative bodies (GWP, 2006).

Since most countries in the Middle East and North Africa can be classified as having absolute water scarcity, and water demand from all sectors is expected to increase (Studer et al., 2002), IWRM is of particular importance in the region. Governments are currently the most active institutions in managing regional water resources; IWRM approaches, however, require participation of the different water users in managing water resources. Therefore, the role of governments will change from managing water resources to regulating the institutions involved in managing them. Regulations and laws will have to be adapted accordingly.

Efficiency of water use in agricultural production. Improving water-use efficiency in agriculture will have to include technical, economical, institutional and social options. Technical options include improving the infrastructural and organizational aspects of water conveyance and distribution systems; on the farm, they include improving the scheduling and practices of applying water in irrigated cropping—and making better use of precipitation in rainfed production. Since many farmers in CWANA may not be in the position to finance more efficient irrigation technology, they may have to be encouraged and assisted in moving toward more water-efficient systems. Furthermore, education and training will be needed to implement more water-efficient practices. However, water-demand management options such as water pricing developed with the participation of water users will have to complement technological options. Organizing users in water-user associations has proven effective in improving water management.

*Water harvesting. C*ollecting, storing and concentrating precipitation at different scales (water harvesting) is an ancient technique dating back 4,000–5,000 years. It is currently under revival in response to the escalating water scarcity (Falkenmark et al., 2001). Harvested precipitation, i.e. collected runoff water, may be either diverted directly to the cropped area during the rainfall event ("runoff farming") or may be collected for irrigation or other purposes such as domestic use or livestock watering (Oweis et al., 1999). Runoff farming and using stored water for irrigation may be practiced at micro, meso and macro scale, and numerous technologies have been developed according to specific environmental and sociocultural conditions (see Critchley et al., 1991; Agarwal and Narain, 1997; Prinz et al., 2000; Prinz, 2002; Prinz and Malik, 2002; Mahnot et al., 2003; Oweis et al., 2004; CSE, 2006). Other water-harvesting techniques include floodwater harvesting, fog and dew harvesting, and groundwater harvesting by qanats, underground dams or special wells.

Water harvesting may not only tap unused water resources and thereby increase crop productivity and minimize the risk of crop failure in dry areas, it may also allow producing crops in environments where cropping is not feasible without such technologies. Furthermore, water harvesting may facilitate forestation or reforestation, fruit tree planting or agroforestry, and protect land from degradation and desertification (Prinz, 2002). Groundwater recharge for more sustainable use by different sectors represents another important benefit of water harvesting.

However, it is not clear if widespread use of water-harvesting technologies is achievable, since construction and maintenance costs, particularly the labor costs, are generally important. Furthermore, many water-harvesting projects require collective action at community or watershed level, and land lost for catchment areas represents an opportunity cost that may deter small-scale farmers in land-scarce areas from adopting water-harvesting technologies (Rosegrant et al., 2002b). Since certain technologies may require inputs that are too expensive for some farmers to supply, some intervention of state authorities may be needed (Prinz, 2002).

As rainwater harvesting should be an integral component of a farming system, a systems approach has to be followed and water-harvesting technologies should be combined with other improved management practices such as adequate fertilization, pest management, improved varieties, crop rotations, and efficient irrigation techniques. Applying remote sensing data and hydrological models at watershed level may not only facilitate the identification of suitable water–harvesting sites and technologies but also help prevent problems between upstream and downstream water users and allow for supplying sufficient quantities of water for natural flora and fauna.

Since water harvesting operates at both household or farm scale and community or watershed scale, farming systems research must consider institutional and land-tenure issues, in which traditional and formal institutions may play a crucial role. Little research has been carried out in this respect, and thus AKST still faces important biophysical and socioeconomic knowledge gaps with regard to water harvesting. Extension and irrigation staff require more knowledge about water-harvesting techniques and the associated socioeconomic implications to achieve the potential gains in crop yields from water harvesting in combination with supplemental irrigation and improved farm management practices (Falkenmark et al., 2001). Since water-harvesting technologies originated in CWANA, a wealth of indigenous knowledge exists in the region that can be used to develop new practices and improve the efficiency of systems still in use today. For widespread adoption of such technologies, however, land-tenure systems will have to accommodate ownership or long-term use rights, so that farmers will be willing to invest in water-harvesting systems. Policies should encourage the required inputs for construction and maintenance.

Use of unconventional water resources. Rather than seeking pristine new water sources, a wide range of alternative water supplies will increasingly be used to meet demands. Reclaimed water, gray water, fog collection, recycled water, brackish water, saltwater, or desalinated water may all be considered usable for particular needs, and in fact may have environmental, economic or political advantages. Reclaimed water such as treated wastewater can be used to recharge groundwater aquifers, supply industry, irrigate certain crops, or augment potable supplies (Gleick, 2000).

However, using unconventional water resources may pose its own problems. Treated wastewater used in agriculture might entail health hazards and water-quality problems, requiring regulations regarding its treatment and reuse. Such regulations will particularly have to cover the responsibility of water polluters in treating their wastewater to make it safe to use (e.g. in agriculture) or to discharge into the environment. More training for farmers, water users and crop consumers will be needed to address issues related to health and water quality aspects.

Groundwater recharge. Groundwater resources are being overexploited in most CWANA countries (FAO, 1997; Aquastat, 2006). This is due to over pumping and also to reduced recharge related to diminishing infiltration rates caused by expansion of urban areas, inadequate land management, and climatic changes (Morris et al., 2003). Water-table elevations are dropping and seawater intrusion is becoming a common problem in many CWANA countries.

Maintaining and increasing aquifer recharge may counterbalance increased exploitation to a certain extent. Foremost, it is important to enhance natural recharge by adequate land management, i.e. by reducing runoff of precipitation. This may not only increase aquifer recharge but will also allow storing a greater part of the scarce precipitation in the soil for crops to use and will reduce erosion. The high evaporation rates in the CWANA region make groundwater storage particularly advantageous (UNEP/IETC, 2001).

Artificial recharge of groundwater aquifers is also a viable option. Artificial recharge can be achieved through surface spreading and preventing runoff or by direct well injection into the groundwater. Sources of recharge water may include precipitation and storm runoff, trapped from cultivated and uncultivated land, from urban areas, surface water, leaks in water supply systems, over irrigation, or treated wastewater (Morris et al., 2003; NEIWPCC, 2003). Artificial recharge may require temporary storage structures and water treatment in sedimentation tanks to improve water quality, particularly for treated wastewater. As a rule the quality of water recharged into an aquifer should be at least equal to or better than that of the groundwater, and water quality should be regularly monitored.

Water demand management. Options for managing water demand include technical, financial and economic measures, public awareness and active public participation in addition to institutional and legal measures (Gleick, 2000; Baroudy et al., 2005). Technical options for demand management include improving water infrastructure, rehabilitating existing water conveyance and distribution systems, lining earth ditches with concrete or other materials, replacing irrigation ditches with pipelines where affordable, rehabilitating old irrigation wells, rehabilitating hydraulic structure and irrigation networks, and installing water-measuring devices. At farm or field level, shifting to more efficient irrigation systems, improving irrigation practices, irrigating with proper scheduling, using unconventional water sources, cultivating more drought- and salinity-tolerant crops, and diversifying production systems with new crops and rotations that are more conservative in water use (Hillel, 2000) may reduce water demand considerably. Knowledge and understanding of farmers with regard to water-efficient technologies and practices will therefore have to be strengthened and increased.

However, besides technological options, demand for water will also have to be reduced through economic, administrative and social mechanisms (Baroudy et al., 2005). Whereas incentives may encourage investments into water-efficient technologies, water tariffs and water prices have a direct effect in controlling demand. In CWANA, farmers often have little reason to save water because irrigation water is easily accessible and farmers do not have to pay much for the water they use. Water-pricing policies may thus be efficient in general but remain highly controversial in the region. Therefore, water pricing should be used within a comprehensive framework to follow an IWRM approach in managing water resources. Usually water pricing includes the cost of water treatment where required, distribution and conveyance. It is important that water-pricing policies be developed with the participation of water users.

Financial and economic measures should be governed by two main principles: the user-pays principle and the polluter-pays principle. The water value should exceed the marginal cost of extracting and distributing the water. Water tariffs should be based on the full economic cost of the water; they should cover full operation and maintenance costs for the system. Flat tariff systems should be eliminated and farmers should be charged according to their actual consumption of water. Being charged by water consumption per unit area for irrigation gives farmers incentive to improve their water-use efficiency. Water cost from different sources and for different areas should be calculated according to the same principles.

Raising the degree of public awareness about rational water use and consumption patterns is important for effective demand management. A more promising approach than simple public campaigns is to strengthen the public's participation in controlling water demand and use, i.e. decentralization and participation in decision making regarding water management. Devising appropriate institutional frameworks adapted to the specific requirements and conditions of each country can establish and empower water-user associations, which have proven to increase water users' awareness and responsibility.

Virtual water trade. "Virtual water" is the water used to produce an agricultural product. Trade in agricultural products is thus also trade in virtual water. Trade of virtual water at national and particularly at international levels may reduce the pressure on scarce water resources and improve water-use efficiency globally (see World Water Council, 2004). By importing products requiring large amounts of water for production from areas with abundant water resources, water-scarce countries and areas may reduce the pressure on their own water resources and thus make water available for other purposes—the principle of comparative advantage. If the goods are imported from countries where less water is required to produce them, the global productivity of water may be increased. Since pressure on water resources may be eased through virtual water trade, investments in developing new water sources (such as dams or water transfer) may be reduced and negative side effects thereof diminished. Furthermore, the potential for conflict over water, which is particularly prominent in CWANA, may be reduced through virtual water trade (Allan, 2002).

However, virtual water trade also bears potential risks and drawbacks. These include ecological aspects (related transport, nutrient transfers, sustainability of production in exporting countries, alternative land use in importing countries) and economic concerns (how to afford imports; effects of imports on local agricultural production, rural development and consumer prices). Furthermore, opportunity costs of land and labor, as related to high unemployment rates, will have to be considered carefully in designing policies relating to virtual water trade. The greatest obstacle to the concept, however, lies in sociopolitical aspects, particularly in the geopolitical situation of most CWANA countries. People and countries are in general reluctant to become dependent on food imports; they may feel they will become restricted in autonomy and self-reliance. Thus implementing the virtual water concept requires consideration of important national goals such as food security (self-sufficiency or self-reliance), national security, economic growth and development (including poverty reduction, employment opportunities) and the quality of life in general. The virtual water concept may thus foster a more holistic approach to managing water resources, by linking water, food production, trade, consumption, food security, etc. It is a useful theory for developing policies targeting more productive water use and rational water-resource management.

However, research is still required to fill knowledge gaps on potentials and risks related to the concept. In addition, agreements on enabling framework conditions would have to be elaborated and implemented at international (WTO) level. Such agreements would have to consider political, social and ecological aspects, assure the food security of importing countries and provide protection from abuse of dependencies through blackmail (Studer, 2005).

5.2.2.2 Soil and land

Since productive soil is the basis for agricultural production, soil and land degradation directly affects agricultural productivity and thus sustainability and development issues such as food security, nutritional quality, poverty reduction and overall development toward improved livelihoods (Steiner, 1996; Scherr, 1999; Penning de Vries et al., 2003). Furthermore, adequate soil management offers considerable opportunity for increased carbon sequestration, which may in turn mitigate climatic changes and their adverse effects on agricultural production and resource degradation.

Causes of soil and land degradation are closely related to numerous socioeconomic factors such as population growth and changing consumer habits; unprofitable farming due to low yields, high input cost, low farm-gate prices, and lack of access to markets; high risk, discouraging investment; and insecure land tenure and user rights (Studer et al., 2000). It has become apparent that AKST has to put more emphasis on tackling the reasons behind soil and land degradation, as well as developing and disseminating sustainable land-management practices that fit specific conditions.

Interventions to avoid, reduce and reverse soil and land degradation are required at different levels, and have to be coordinated and synchronized (Steiner, 1996). Most obvious are interventions at *plot or field level*. Numerous practices and technological options fostering sustainable land management are available through both traditional and modern knowledge. However, options such as cover cropping, terracing, green manuring, conservation tillage and rotations with leguminous crops have to be adapted to the specific agroecological and socioeconomic conditions of the farm enterprises. This requires trial and evaluation methods that can be extrapolated to other locations. Modeling approaches supply information more rapidly than field trials and are considerably less costly. Further, various case scenarios may be simulated and explored, and results may be upscaled or transferred to other environments, particularly if modeling is combined with GIS or remote sensing. However, modeling approaches require a solid database, which in many countries of the region is not yet established.

A major problem with regard to sustainable land management is that the profitability of particular measures is often low or not directly obvious, especially in view of such continuously rising opportunity costs as labor. Technology development has therefore to focus on satisfying the short-term economic interest of *farmers and households*. Focus on promoting sustainable land use will thus have to shift to increasing productivity by maintaining, improving and stabilizing yields rather than on conserving soils (Scherr, 1999). Furthermore, technologies introduced will have to be compatible with the farmer’s farming system and risk-avoidance strategy. Risk reduction is a particular primary concern for smallholder farming in the adverse environments of CWANA dry areas. Thus farmers may find quite acceptable recommendations that do not necessarily improve profitability but promise greater yield security and stability (Steiner, 1996).

For many interventions focusing on soil and land management a *community or watershed* approach will be necessary. Land-use planning, possibly coupled with changes in land tenure, zoning rules, control of agricultural land conversion and management of common lands, involves issues that are typically dealt with at this level (Scherr, 1999). Particularly in marginal lands, spatial concentration and intensification of production should be encouraged to achieve more profitable production and simultaneously protect fragile land from degradation (Scherr, 1999). Improving present land use and identifying alternatives to inappropriate land use have to be negotiated in a multilevel stakeholder approach, in which it is important to integrate local authorities and national administrations (Hurni et al., 1996). Participatory approaches and the formation of farmer or land-user associations, village committees or cooperatives may facilitate mutual understanding and collective action (Steiner, 1996; Penning de Vries et al., 2003).

At *national level*, policies and legislation relating to socioeconomic issues and institutional aspects regarding agricultural research and extension will play a major role for achieving more sustainable soil and land management. Flanking measures to reduce the demographic pressure of high population growth rates may relieve pressure on land (Steiner, 1996). Generating nonagricultural employment opportunities, agricultural opportunities in other areas and opportunities in forest management (Scherr, 1999) may contribute to increased income in rural areas. This change for the better should in turn favor investments in agriculture, often facilitating measures and practices for more sustainable land use. Developing credit and savings schemes may help farmers organize and finance investments in land improvements and conservation.

The effects of pricing policies regarding inputs and outputs as influenced by market liberalization and protective measures, tariffs and taxes, or other incentives and charges may vary in different countries. Higher producer prices often stimulate investment in agriculture and may thus lead to increased productivity and more sustainable land management. Ensuring market access for farmers is prerequisite for pricing policies to produce impact, often requiring infrastructure development. Internalizing such external effects of land degradation as off-site costs of erosion (Steiner, 1996; Penning de Vries et al., 2003) and recognizing the multifunctionality of agriculture may assist in appropriate pricing policies.

Land tenure legislation must guarantee long-term land-use rights to owners and leaseholders if land users are expected to invest in long-term soil conservation measures. However, often such rules need to be tailored to such local conditions as traditional land rights and the interests of different stakeholders. Local institutions are generally in a better position to adapt and enforce such regulations than national entities. The value of land is an essential component of land law because it greatly determines the commitment of land users to use this production factor in a sustainable way (Steiner, 1996).

Another important domain of national policy relates to agricultural *research and extension*. To assume their task of solving the problems of land users, researchers and extension agents require a clear definition of target groups and recommendation domains, and precise information on the decision-making criteria of land users, who often apply decision-making measures other than those specialists use. Participatory technology development may foster the adoption of interventions (Steiner, 1996); improve integration of research, technology development and extension; and facilitate learning from and disseminating results of successful land management practices and approaches (Steiner, 1996; Penning de Vries et al., 2003). Initiatives such as WOCAT (World Overview of Conservation Approaches and Technologies) or IASUS (International Actions for the Sustainable Use of Soils) and UNCCD may further facilitate such exchange and allow for enhanced cooperation (Hurni et al., 1996, 2006). Drawing on local farmers' know-how and traditional indigenous techniques may facilitate development of appropriate adapted technologies (Steiner, 1996). Remote sensing, GIS and time-series data may allow for exploration of relationships between soil-quality changes and farm management, local economic and social conditions, and the policy environment. Thus soil-related information may be incorporated in economic and policy modeling for more holistic and integrated analysis of problems and solutions, and allow for the evaluation of different scenarios and identification of priority areas for action (Scherr, 1999; Penning de Vries et al., 2003).

In summary, approaches to avoid and reverse soil and land degradation should generally consider

- Following a participatory, multidisciplinary systems approach (sectorwide thinking; Scherr, 1999)
- Following the principle of subsidiarity in decision making (decisions should be delegated to the lowest possible level) (Hurni et al., 1996)
- Fitting and targeting the specific environment (regarding development pathways, farming systems, soil types, degree of degradation, etc.; Scherr, 1999)
- Combining indigenous traditional wisdom with modern knowledge and technologies (such as remote sensing, GIS, and simulation modeling)

With regard to the rational management of soil resources, AKST in CWANA will have to target the following major focus areas:

- *Increasing or maintaining soil fertility and quality*. To counteract negative nutrient balances in many CWANA countries, AKST will have to focus on more efficient use of nutrients, e.g. by developing nutrient management systems for specific soils (Scherr, 1999) or by splitting fertilizer applications. Nutrient inputs will have to be increased, requiring access to and affordability of mineral fertilizers; the complementary use of organic fertilizers from crop residues, manure, compost and green manure will have to be encouraged; and the benefits of biological nitrogen fixation through legumes in rotations, green manure or cover crops will have to be better exploited. Increasing problems of micronutrient deficiencies and depletion will have to be explored and solved. Loss of nutrients will have to be avoided wherever possible by rapidly incorporating manure, combating erosion, etc. Ways will have to be explored to better close nutrient cycles by recapturing nutrients currently discarded in water bodies or dumped as waste elsewhere.

- Adequate *organic matter management* is particularly essential in CWANA since organic matter decomposes rapidly in high temperatures. Organic matter increases nutrient availability through direct addition and may enhance nutrient use efficiency by improving cation exchange capacity (CEC). Furthermore, increasing the organic matter content in soils improves water-holding capacity, which is extremely important in the dry areas of CWANA, and enhances soil structure, which reduces susceptibility to wind and water erosion and promotes soil fauna and flora. Increasing organic matter in soils also presents a big opportunity to act as a sink for carbon sequestration, thereby offering potential to mitigate global warming.
- *Combating wind and water erosion* remains a major challenge in CWANA. Cropping systems, rotations and cropping practices aiming at year-round soil cover should be envisaged wherever possible, although this is not always possible in the dry areas of CWANA. Using harvest residues in mulching, strip cropping (possibly with perennial vegetation), bunds, ridges, terraces, etc., will have to be promoted and profitability of suggested measures assured. Conservation tillage and economically productive cover crops or perennials integrated in crop rotations may be as economical as conventional cropping. Developing low-cost soil conservation and rehabilitation techniques such as control of water flow over land will have to receive major attention (Scherr, 1999).
- *Protecting and conserving vegetative cover and quality*. Since vegetative cover is key to soil protection, maintaining and—where required—restoring flora and fauna are fundamental for sustainable land use (Scherr, 1999). Appropriate grazing management and protection of land susceptible to degradation (e.g. against inappropriate cropping) will have to receive particular attention in the future.
- Practices to *avoid salinization* of highly productive irrigated land are well known and consist of improving system- and farm-level water management regimes and the necessary investments in proper drainage systems. AKST will have to investigate diversification options into higher-value crops to justify the required investments. Methods to use saline lands and low-cost options to control or reverse salinization will also have to receive major attention (Scherr, 1999).
- *Reducing pollution* of soils (as well as of water and air) is particularly important in the more intensive production systems that will probably develop in many areas of CWANA. In this regard, regulating the use of agrochemicals and disposing of agrochemical and livestock waste will have to play a major role in protecting agricultural soils from pollution (Scherr, 1999). Raising awareness and understanding about pollution problems will have to accompany such regulations; lessons learned in other, industrialized parts of the world will be of particular value.
- Particularly challenging with regard to sustainable land management is the *development of new lands*—reclamation of land never cultivated before, such as practiced in Egypt. Whereas

such new lands hold considerable potential, because their low disease, pest and weed pressure raise the opportunity for organic production, their development may bear great difficulties, in particular with regard to building up and maintaining soil fertility and the high susceptibility of marginal lands to degradation.

- Stopping *sand encroachment* will represent a major task with regard to protecting productive soils in many countries of CWANA (Dupuy et al., 2002; ACSAD et al., 2004). Many different methods of combating this phenomenon are known (for a review see Ramadan and Al Sudairawi, 2005), which allows AKST in CWANA to capitalize on lessons learned not only in the region but also in Sahelian countries and in China and Mongolia.

5.2.2.3 Biodiversity

Biodiversity is undoubtedly being lost in many parts of the globe, often at a rapid pace. This loss poses a serious threat to agriculture and the livelihoods of millions of people. Conserving biodiversity and using it wisely is a global imperative. Biodiversity provides the foundation for our agricultural systems. It provides the sources of traits to improve yield, quality, resistance to pests and diseases, and traits than can adapt to changing environmental conditions such as global warming.

Loss of biodiversity requires countermeasures such as increased efforts toward conservation by different means (see table 5.2). Conservation may be in situ or ex situ, in either natural or seminatural habitat, or in some purpose-built environment (Braun and Ammann, 2002). The choice of one technique or the other, or a combination of both, will depend on the particular case. In situ conservation will involve maintaining and protecting natural habitats, while botanical gardens and seed banks are used for ex situ conservation. Both of the latter require precise knowledge of taxonomy. Today, conservation also embraces various components of agrobiodiversity like crop varieties, landraces, semidomesticates and crop relatives. The methods of biotechnology can be applied to the study of virtually any biological phenomenon and will in some cases have practical applications for maintaining biodiversity. Conversely, threats to biodiversity by biotechnology also need to be considered.

[INSERT Table 5.2]

Different approaches to conserving biodiversity and different ways of using genetic resources are described here in more detail. One approach is on-farm management that involves maintaining crop species on farms or in home gardens; ICM may play an important role in this approach. Wild populations regenerate naturally and are dispersed naturally by wild animals and winds and in water courses. A second approach is the in situ conservation of forests and other wild plant species, often carried out through, but not limited to, designated protected areas such as national parks and nature reserves. In addition and depending on the type of species to be conserved, different ex situ conservation methods may be used. A complementary conservation strategy can be defined as “the combination of different conservation actions, which together lead to an optimum sustainable use of genetic diversity existing in a target gene pool, in the present and future” (Bioversity, 2007). It should not be forgotten that the main objective in any plant genetic resource conservation program is to maintain the highest possible level of genetic variability present across the gene pool of a given species or crop, both in its natural range and in a germplasm collection.

Plant genetic resource conservation and use may greatly benefit from applying modern developments in molecular genetics. CWANA countries could benefit from the program the International Plant Genetic Resources Institute (IPGRI) has identified, which includes the following components (IPGRI, 2001):

- Capacity building, with an ultimate goal of providing the genetic resources community with tools in the molecular area, emphasizing development in the context of research, gene bank management and germplasm use.
- Research that includes information on genetic diversity and location of useful genes and alleles in germplasm collections.
- Storage, management and analysis of molecular marker information obtained from screening germplasm collections and linking this information to existing traditional data.
- Policy and biosafety where IPGRI closely monitors developments and helps partners in national programs to define their stance for issues related to the conservation of diversity, proprietary concerns and protection of the environment.

Modern information technologies such as GIS used to characterize the geographical distribution of wild plants, or new electronic technologies for monitoring the environment such as Planetor, a computer program for analyzing environmental problems (Hawkins and Nordquist, 1991) may greatly contribute to conserving the environment and biodiversity. But new strategies and policies to conserve the biodiversity and improve research on biodiversity are additionally required.

Efforts on biodiversity conservation can learn from context-specific local knowledge and institutional mechanisms such as cooperation and collective action; intergenerational transmission of knowledge, skills and strategies; concern for well-being of future generations; reliance on local resources; restraint in resource exploitation; an attitude of gratitude and respect for nature; management, conservation and sustainable use of biodiversity outside formal protected areas; and transfer of useful species among households, villages and the larger landscape (Pandey, 2003, 2004).

Traditions are reflected in a variety of practices regarding the use and management of trees, forests and water:

- collection and management of wood and non-wood forest products
- traditional ethics, norms and practices for restrained use of forests, water and other natural resources
- traditional practices to protect, control production and regenerate forests
- cultivation of useful trees in cultural landscapes and agroforestry systems
- creation and maintenance of traditional water-harvesting systems such as tanks along with planting tree groves close by

These systems support biodiversity, although not necessarily natural ecosystems, and help reduce harvest pressure (Pandey, 2004).

Traditional knowledge associated with biological resources is an intangible component of the resource itself. Traditional knowledge has the potential of being translated into commercial benefits by providing leads for developing useful products and processes. These valuable leads save time, money and investment of modern biotech industry into any research and product development. Hence, a share of benefits must accrue to creators and holders of traditional knowledge.

Options for protecting traditional knowledge, innovations and practices include (1) documentation of traditional knowledge, (2) a patent system for registering innovations, and (3) development of a sui generis (only example of its kind) system (WTO, 2000).

5.2.2.4 Livestock and fish

The threat of extinction for many species, both known and as yet undiscovered, grows ever greater as whole ecosystems vanish, human populations proliferate, and human-mediated interference increases (Ryder et al., 2000). Whereas a laudable effort is being made to organize seed banks for plants, no such organized attempts to store genetic material exist for many species of either vertebrate or invertebrate animals. There are worldwide attempts to coordinate and store samples of DNA for every endangered animal species in DNA libraries or to freeze cells or tissues that could readily yield DNA for captive breeding programs.

Captive breeding provides an insurance strategy against extinction and for some species may be the only hope of survival. It requires input from population genetics to preserve high levels of genetic diversity, and from reproductive physiologists to promote the establishment of pregnancies, for example by artificial insemination. Cryopreservation of gametes and embryos has a role to play, while in the future, nuclear replacement cloning from established cell lines might prove of value. Such strategies may succeed in saving a small fraction of endangered species, at least for a time (Ryder et al., 2000). These tools will be particularly powerful when used in conjunction with efforts to conserve the habitats in which populations restored by DNA techniques can live.

West Asia and Mediterranean North Africa are endowed with considerable genetic diversity in small ruminants—various breeds of sheep and goats that are adapted to a range of arid and semiarid environmental conditions. But these local breeds may be endangered through intensified production systems and uncontrolled crossbreeding with exotic breeds. Therefore, it is important to think of possible ways to conserve the genetic diversity of these local breeds, which may be valuable in the future.

One way of preserving genetic diversity is ex situ conservation by storing frozen semen in gene banks. Another way is in situ conservation. The best way forward would be a combination of both conservation approaches, but the costs of ex situ conservation might be high. Storage facilities could be shared by different countries, thus reducing costs for each country.

In aquaculture, broodstock is either obtained from the wild or domesticated in the hatchery. Depending on the wild is not enough for optimum aquaculture production. In the hatchery, broodstock must be managed to ensure genetic resources are conserved, to maintain the desirable characters of the farmed species and to avoid problems of inbreeding (Bartley, 1998).

Genetic processes such as hybridization, chromosome set manipulation and sex reversal are used in aquaculture to improve breeds. Genetic technologies can be also used to reduce the environmental risks of exotic species escaping from the aquaculture facilities. To reduce the effects of changing genetic resources of organisms produced in hatcheries, several protocols have been prepared that demonstrate the best methods for choosing the origin and number of parents from specific fish species.

5.2.2.5 Institutional considerations

CWANA member countries are encouraged to become party to the International Treaty on Plant Genetic Resources for Food and Agriculture if they have not already done so. Its objectives are the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security.

CWANA countries are to benefit from IPGRI efforts that support the conservation and use of neglected and underutilized crop species. IPGRI assesses the diversity and conservation status of a wide range of neglected crops through participatory regional programs, and implements activities to enhance both these varieties and their marketing. Neglected and underused crop species—also known as orphan crops—have been overlooked by scientific research and by development workers, despite the fact that they play a crucial role in food security, income generation and food culture for the rural poor. This lack of attention means that the potential value of these crops goes unrealized. It also places them in danger of continued genetic erosion and ultimate disappearance, further restricting development options for the poor. IPGRI is attempting to safeguard the genetic resources and associated knowledge through ex situ and in situ conservation across the CWANA region in areas where their genetic diversity is highest, like in Turkmenistan, Syria and Tunisia. In addition, IPGRI is improving its understanding of the agromorphological and market-driven traits and exchange of materials and experiences across countries, which will strengthen country capacity in commercializing and promoting the multiple uses of such crops.

The goal of ICARDA's Genetic Resource Unit is to conserve and use the biodiversity of ICARDA's mandate crops: wheat, barley, lentil, kabuli chickpea, faba bean, and pasture and forage species and their associated rhizobia. Its gene bank serves as a repository for a world collection of these crops and their wild relatives; crops that are of vital importance, not only to the CWANA region, but to the world at large.

With regard to conserving the diversity of threatened and wild fish species, different international organizations working with fisheries such as the Food and Agriculture Organization of the United Nations (FAO) have made efforts to change the criteria for adding new marine species to the list of endangered species. Fishery authorities in the countries concerned were also encouraged to participate in the convention in related subjects. Marine protected areas are well placed to conserve fish biodiversity as they can protect critical habitats. The Convention on Biological Diversity was ratified in, 1995 with the main objectives of conservation of biological diversity and sustainable use of its components. This convention plays an important role in conserving aquatic biodiversity. The FAO Code of Conduct for Responsible Fisheries (CCRF, also ratified in 1995) is another important tool for conserving aquatic biodiversity. Both CBD and CCRF have similar articles regarding the introduction of alien species. Both treaties encourage countries to notify their neighbors about any introduction and to establish a database or information system regarding introduction of aquatic organisms. They both also encourage the countries to monitor the aquatic environment and conserve genetic diversity. Countries should develop a code of best practices for responsible introduction of alien species.

Other actions that could be envisaged at CWANA country level to foster the conservation of biodiversity:

- developing national genetic resources legislation
- establishing an IPR system
- placing NBSAPs in the mainstream of the national development plans of the country
- synergizing implementation of CBD action plans and other conventions such as UNCCD and the UN Convention on Climate Change
- Becoming party to the Cartagena Biosafety Protocol to safeguard against GMO release through transboundary movement

5.2.3 Capacity development and knowledge management

Insofar as scientific and technical progress in the region is concerned, a number of trends and opportunities have occurred: the adoption of new technologies, particularly biotechnology and ICT, privatization of state-owned enterprises and trade liberalization, a greater role for development agencies in agricultural and rural economies, and increased international collaboration through the ecoregional approach and South-to-South programs (IPGRI, 2001).

Advances in scientific knowledge across a broad range of disciplines will be required to develop more and better food and fiber products with improved nutritional quality, to reduce food and commodity yield losses due to pests and diseases; ensure healthy livestock, sustainable fisheries, aquaculture and forestry sectors; manage water more efficiently; prevent and reverse land degradation; and conserve and manage genetic diversity (El-Beltagy, 2005).

A focused and appropriate research agenda is required to meet these challenges that are supported by public investment. Unfortunately, public investment in agricultural research and development is declining, while private sector investment is increasing in the OECD (Organization for Economic Co-operation and Development). Private sector investments tend to focus on commodities produced for OECD markets and often neglect the needs of the poor. Thus increased investment by the private sector will not meet the demand for diversified agricultural products and improved rural livelihoods via the required multisectoral approach that covers economic, environmental, ethical and social considerations.

Given the decline in public sector investment in developing countries at a time when the challenges to apply science and technology are urgent, there is a need to consider carefully the agenda for future agricultural research and development efforts. This agenda must also include public debates on controversial issues such as the development and deployment of genetically modified organisms and other aspects of modern biotechnology (Thomas et al., 2003).

In a study conducted by the World Bank and FAO in ten developing countries (Rivera et al., 2005) including three CWANA countries: Egypt, Morocco, and Pakistan, it was concluded that these countries do not yet appear to possess a totally integrated and operative agriculture knowledge and information system (AKIS), although all appear to want to move in that direction and be making significant progress. Agricultural education, research and extension still tend to operate as three separate systems (or subsystems).

In the following section we address capacity development options to support sharing, exchanging and disseminating knowledge generated through AKST systems in its subsystems of education, research and extension, and to integrate these subsystems in the CWANA region. The emergence of ICT in the last decade has opened new avenues in knowledge management that could play important roles in meeting the prevailing challenges relating to ICT and knowledge management.

5.2.3.1 Information and knowledge produced by AKST institutions

The ultimate objectives of AKST activities are to come up with results that can advance research more in certain areas, and engender technologies that AKIS stakeholders can use to increase production, conserve the environment, etc. The following subsections describe the options proposed to meet challenges related to sharing, exchanging and disseminating knowledge and technologies generated from AKST activities and that are most needed by growers, extension workers, researchers and decision makers.

Mechanisms and infrastructure for *sharing and exchanging* agriculture knowledge generated from research at national and regional levels should be enhanced. Many research activities are repeated due to the lack of such mechanisms and infrastructure at the national level. Researchers can find research papers published in international journals and conferences more easily than finding research papers published nationally in local journals, conferences, theses and technical reports.

Mechanisms and infrastructure for *transferring technologies* produced as the result of research to growers either directly or through intermediaries (extension subsystem) should be strengthened.

Knowledge and technologies fostering agricultural production and environment conservation are examples. Although many extension documents exist in the region, produced by national agriculture research and extension systems to inform growers about the latest recommendations concerning different agricultural practices, these documents are not disseminated, updated or managed to respond to the needs of extension workers, advisers and farmers. This is also true for technical reports, books and research papers related to production.

Indigenous knowledge must be kept as a heritage for new generations. It is available through experienced growers and specialists in different commodities. These inherited agricultural practices are rarely documented, but they embody a wealth of knowledge that researchers need to examine thoroughly.

Economic and social knowledge must also be made easily accessible to different stakeholders at operational, management and decision-making levels, so that those responsible will be able to make appropriate decisions regarding the profit making of certain technologies and their effect on resource-poor farmers.

All these types of knowledge must be made available to the *education subsystem* to keep students up to date with the latest developments.

5.2.3.2 Integration of education, research and extension subsystems

In a case study conducted by ICARDA (Belaid et al., 2003), recommendations are made to strengthen stakeholders links in national agricultural systems in CWANA. To achieve strong and reliable links among all agricultural stakeholders, the different AKST institutions must be strengthened. The following options are proposed to strengthen these institutions in the CWANA region.

Option 1: Develop institutional capacity. Throughout the priority-setting process that ICARDA provided in the CWANA region in 2003 (Belaid et al., 2003), it became clear that these institutions were not well equipped in resources, organization and representation to adequately address the priority needs of the region. It is therefore essential to strengthen these institutions to enable them to fully play their role in implementing, disseminating and diffusing information that can be used in practice. The acute lack of capacity in other key disciplines such as social sciences, combined with the shift in research focus towards relatively "new" issues such as alleviating poverty and managing natural resources requires capacity development to meet this gap of AKST to adequately implement the subregional research agenda.

Option 2: Develop agricultural extension. Agricultural extension is needed in the CWANA region to educate professional agriculturists (including farmers) who may further enlarge or refine this body of knowledge.

Option 3: Improving agricultural education. Agricultural universities and institutes need to adopt and reorient curricula for new requirements with special training programs in extension development and education and new technologies. Education and training should embrace new scientific achievements and innovations. A full comprehensive training cycle, integrated with science, can ensure that production systems adopt the outputs. New methods of delivering services and new schemes of organization of training that result from the revolutionary changes in information and telecommunication areas (distance and correspondence learning) will be able to cover all levels of rural society. Using a complex approach in education as a unified system should take into account the inputs at all levels in the education hierarchy, including higher (universities and institutes) and secondary vocational education (colleges and academic lyceums) that contribute to development of agricultural education and human capacity as well as humanitarian and social capacity, and their role in renovating, reorganizing and reorienting agricultural production systems. Technical renovation of laboratory and experimental equipment, facilities and materials could be achieved by creating conditions suitable for research and experiments in the classroom and in the field. This could be achieved through providing specialized machinery, equipment and tools necessary for experimental activities. Private investment and funding affect the focus of the education; research and extension result in new subjects and specializations being added to the curriculum. Therefore, integrating such subjects as “international trade” and “agricultural products marketing” means finding staff with the necessary qualifications, knowledge and skills to teach these subjects or retraining staff to do so.

Higher education institutions must have their own production farms to give the students and farmers practical training and research sites for researchers. Creating this kind of training centers that are linked simultaneously to higher education and retraining of specialists is extremely important for strengthening and developing farmers’ movements. AKST systems of different countries have their own development priorities and programs. Collaborative scientific programs may stipulate that the national system must act jointly on a specific crop or aspect of scientific research. Such program requirements will affect the agricultural education system and the entire process of developing innovations. Methods should be developed and shared among CWANA countries, possibly in well-known universities and research centers in the region.

Integrating education, research and extension is a principal task for CWANA to accomplish to achieve its sustainable development goals. Figure 5.2 shows a scheme for integrating education, research and extension. The following paragraphs address options for strengthening the integration of AKST stakeholders:

[INSERT FIGURE 5.2]

Option 1: Involvement of AKST stakeholders. The gap analysis has identified the insufficient involvement of many AKST stakeholders (Belaid et al., 2003). Considering the mandates of these institutions and the important contribution they could make to improving agricultural production and developing capacity of the region, their involvement in the region should be significantly enhanced (box 5.1).

[INSERT Box 5.1]

Option 2: Regional cooperation. To reorient regional cooperation and facilitate implementation of the identified regional AKST institutions, some key approaches were identified, such as networks, coordination meetings and traveling workshops. Existing networks, such as among universities and research institutes, need to be reviewed and consolidated. International centers in CWANA like ICARDA may facilitate such reviews and consolidation. Joint projects (interuniversity, between research centers) can enhance regional collaboration and cooperation, through various types of projects that include education, research and extension. The key innovation of the CWANA regional priority-setting exercise was to set the right conditions for a dialogue where "nontraditional stakeholders", i.e. farmers, NGOs, the private sector and grassroots organizations, would play a central role. CWANA countries have the opportunity to use cooperational links independently, create a special regional association of agricultural education, research and extension institutions, and interconnect them with a unified network. In view of the complexity of challenges facing the region it is unlikely that AKST regional institutions will be able to satisfactorily address them on their own. This in turn highlights the urgency of establishing strategic partnerships to tackle the problems of developing agricultural capacity in the region. The strategic partnership should seek to link the education, research and extension initiatives to the development goals of alleviating poverty and improving food security.

Option 3: Applying a participatory approach. Participatory bottom-up approaches can be done at three levels: (1) regional, (2) CWANA subregional, and (3) North Africa, West Asia, Central Asia and Caucasus. The valuable lessons learned from previous case studies (Belaid et al., 2003; Thomas et al., 2003) have triggered the need to develop mechanisms that will expand collaboration and dialogue through sustainable links and strategic partnerships with "nontraditional" stakeholders, especially NGOs, farmers, grassroots organizations and the private sector—the ultimate clients of agricultural innovation system products and innovations. In national agricultural information systems, the collaborative relationships with universities, NGOs, the private sector, farmers, and farmers' organizations are, by and large, at an embryonic stage and need therefore to be significantly consolidated (Belaid et al., 2003).

5.2.3.3 Agriculture knowledge management using information and communication technology

The central purpose of knowledge management is to transform information and intellectual assets into enduring value (Metcalfe, 2005). The basic idea is to strengthen, improve and propel the organization by using the wealth of information and knowledge that the organization and its members collectively possess (Milton, 2003). It has been pointed out that a large part of knowledge is not explicit but tacit (Schreiber et al., 1999). This is true for knowledge in agricultural science and technology where a lot of good practices are transferred without being well documented in books, papers or extension documents.

To manage the knowledge properly, ICT is needed. A study on using information systems for rural development can be found in FAO (2000) and ICARDA (2006). In CWANA, existing efforts in collecting appropriate knowledge need to be coordinated and made available through ICT to the end users: researchers, extension workers, students and growers. Making this knowledge available electronically on the Web will make it sharable, exchangeable, accessible, and available all the time to these users. Figure 5.3 depicts different channels to disseminate knowledge and information.

[INSERT FIGURE 5.3]

A *database management system* is the core of information and knowledge management. This technology can be used in different applications:

- Building a national agriculture research information system (NARIS) needs to include research outcomes, projects, institutions and researchers in every country, and a regional research information system that works as a portal for all the NARIS. An example NARIS has been developed at the agriculture research center in Egypt (ARC, 2007).
- Managing global market information, analyzing this information, making local market information available on the Internet, assuring product quality control and providing product traceability will help any country gearing toward export-led growth economy.
- Developing an information system of indigenous agricultural practices can enable researchers to examine this knowledge and decide on its usefulness for sustainable development. Such a system will also keep this knowledge for future generations before it disappears as a result of advanced technologies.

- Developing an information system recording matured technologies that on a trial basis have proven successful and success stories that have achieved economic growth will strengthen the interaction between inventors and innovators. This will lead to an innovation-driven economic growth paradigm.

Multimedia information systems are needed to store and retrieve images confirming the occurrence of certain disorders, and videotapes and audiotapes describing how to perform agricultural operations.

Geographic information systems (GIS) are needed to store databases about natural resources with a graphical user interface that enables users to access these data easily using geographical maps.

Decision support system techniques are needed in many applications:

- Simulating and modeling methods can be used to build computer systems that can model and simulate the effect of different agricultural production policies on the economy and the environment to help top management make decisions.
- Using expert systems technology to improve crop management and track its effect on conserving natural resources is elaborated in Rafea (1999). This technology may also be appropriate for keeping indigenous knowledge (Rafea, 1995, 1998, 2000).

Modern ICT—Internet and Web technology—is needed to make these systems available regionally and globally. Accessing the Internet will bring a wealth of information to all agriculture stakeholders in rural and urban areas and will help in overcoming the digital divide.

As most farmers in CWANA have no hands-on experience or access to digital networks, leaders of national agricultural research and extension systems should be encouraged to consider the ICT option. Training farmers and extension workers, including women, in ICT will help them access a lot of useful information if each country tries to develop contents in the language people are using. Box 5.2 describes a case study of using ICT in the WANA region.

[INSERT Box 5.2]

5.2.4 Policy adaptations required to realize options

Many of the options related to technological advances, capacity development and knowledge management, which may facilitate overcoming the challenges AKST faces in CWANA, can only be realized and yield impact if policies are adapted accordingly. Policy adaptations may be required at different levels and in various domains.

5.2.4.1 Land-use and land-tenure rights

Land-tenure legislation must guarantee long-term land-use rights to owners and leaseholders if land users are expected to invest in enhancing the productivity and long-term conservation of land. Land-use planning, zoning rules, and management of common lands require participatory approaches to consider the often-conflicting interests of different stakeholders. Since land tenure and use regulations need to be tailored to local conditions, decentralization may foster community or watershed level approaches that integrate the roles of local authorities and national administrations. Specific adaptations to land-use and land-tenure policies in CWANA might include the following:

- Reduce local government interference in land privatization and land use.
- Review and amend land legislation to ensure that it unambiguously defines suitable land-ownership, use and inheritance rights, and the conditions under which land can be expropriated.
- Strengthen the judicial agencies responsible for land ownership, to ensure that they are independent, transparent and accessible and that they provide adequate protection for land users.
- Develop a legal and institutional framework that ensures that land users and owners have clear, secure rights to use, own and transfer property and that defines and supports the state's role as ultimate land custodian. Future procedures and administrative structures should be low cost, accessible by all, transparent and conducive to the efficient operation of land markets and secured credit transactions.
- Develop a system rights to land ownership, land use and land transfer that ensures that producers have full incentives to increase agricultural production and to use their land in a sustainable manner.
- Ensure that these rights are fully transferred to all producers through the issue of land-use titles, and that producers have the right to choose whether they operate as individual farmers or as collectives, formed according to their preferred means of association (family, village, etc.).
- Develop an active market for selling and leasing land and land-use rights.

5.2.4.2 Integrated water resources management

The coordinated development and management of water and related resources (IWRM) depends to a great extent on developing and implementing appropriate and coherent policies. Pertinent policies should be elaborated with the participation of all stakeholders in IWRM to allow consideration of water demands in sectors other than agriculture. The basic principles of IWRM could be applied through following:

- Promoting transparent decision making, decentralized governance and a participatory approach to water operations under the principle of subsidiarity (at lowest competent authority level).
- Promoting managerial, financial and institutional innovations at all levels including new models of cooperation among the various stakeholders and the introduction of water pricing and water rights to encourage rational and efficient allocation of water, discourage waste, enhance water quality and ensure adequate water services.
- Reconciling the competing objectives of countries and sectors (power operation, flood control, irrigation, industrial and domestic supply, and environment), decreasing conflicts in water use, and supporting regional cooperation and information exchange.
- Fostering demand-responsive versus supply-oriented approaches. This requires that water users and consumers be engaged in selecting, financing, implementing and managing water services that meet their demands and willingness to pay.
- Promulgating policies regarding water-resource management that embrace water-demand management, development of currently untapped water sources, water quality conservation and transboundary collaboration.
- Managing water demand, which may include policies to improve the efficiency of water use in agriculture (e.g. regulations regarding the use of efficient irrigation systems); financial and economic measures such as rational water-pricing options (possibly considering special arrangements for the poor) or the use of incentives and disincentives; and virtual water trade, bearing in mind food security and sociopolitical aspects. Raising public awareness about rational water use and consumption patterns is prerequisite for the implementation and success of such policies.
- Developing currently untapped water sources, concentrating on improving sustainable delivery of surface water by adequate investments and projects, and on using unconventional water resources. Measures for managing economic demand may help finance investments and incentives required to promote innovation and reduce risks related to the development of pertinent technologies and projects.
- Developing or adapting and then enforcing policies related to water quality. This might require investments in monitoring infrastructure and capacity development.
- Collaborating across boundaries to address common problems and appropriate strategies to reduce water shortages through improving the management of water resources. This might require amendments to judicial systems to deal with water disputes and conflicts.

5.2.4.3 Management of genetic resources and biodiversity

Principal policy instruments for conserving and managing biodiversity are land-use planning and zoning, such as establishing protected areas. Modern technologies such as GIS may greatly facilitate adequate land-use planning. Considering international incentives such as the Kyoto FlexMex mechanisms (e.g. the Clean Development Mechanism) may encourage land-use planning that conserves biodiversity. Protection of biodiversity may be linked with adapted land-use opportunities to find solutions acceptable to various stakeholders. Practices in ecoagriculture such as agroforestry, compensation areas and biodiversity-enhancing landscape elements may considerably contribute to biodiversity conservation. Direct payments for functions to conserve and maintain the ecosystem such as biodiversity conservation may encourage farmers to adopt such practices; in some industrialized countries (e.g. Switzerland) direct payments are linked to ecologically friendly land use and management. However, adoption of practices conserving biodiversity is generally dependent on secure land tenure or use rights (e.g. for improved rangeland management. Implementing NBSAPs developed through CBD may facilitate biodiversity conservation as well as make use of this treasure in CWANA. With regard to aquatic resources, the FAO Code of Conduct for Responsible Fisheries serves as an important tool for conserving aquatic biodiversity.

Invasive alien species are a considerable threat to biodiversity and can disturb both agricultural and natural systems devastatingly. Besides policies regulating the importation of living plants and plant material, legislation has to cover aspects such as responsible aquaculture, trafficking of unprocessed wood and use of ballast water.

Furthermore, appropriate biosafety regulations need to be included in country-led sustainable development strategies to face the potentials and challenges related to biotechnology. Policy analysis and development should consider risk assessment, capacity building in research and regulatory systems, and communication and public outreach. Policies should guide research for the poor (e.g. by protecting their intellectual property rights), protect against potential health risks, address possible ecological risks, and regulate the private sector (Pinstrup-Andersen, 1999).

5.2.4.4 Markets and trade

As the markets in which agricultural products compete are changing rapidly, measures to increase output must be accompanied by measures that improve the ability to compete in these markets. The objective should be to add more value rather than produce more, by providing appropriate framework conditions for reorienting and improving production and processing. Only if market organization in CWANA countries is improved will stakeholders in agricultural value chains fully capitalize on increased agricultural production.

- Adequate *input and output pricing* policies are key for enhancing agricultural production while conserving the natural environment. Price stability is extremely important so that farmers can invest and innovate rather than be defensively risk averse. Using targeted subsidies and direct payments (e.g. providing environmental services through agriculture) in the framework of coherent market policies may still be envisaged to promote innovation and more market-oriented production.
- Producers, processors and traders need access to *credits, markets* (to close the gap between rural areas and urban centers) and reliable *market information*, particularly in view of more diversified and market-oriented production. This may enable them to identify and introduce a portfolio of agricultural products that corresponds to consumer demand in major domestic and export markets. Developed public market information services can strengthen the position of various stakeholders in the market chain by providing regular information daily or weekly by newsletter, radio, television or mobile phone on product prices in major regional markets. Adaptation to information policies may be required to let value-chain stakeholders capitalize on relevant information available.
- Appropriate *technologies and infrastructure* are required for well-functioning value chains. Processing facilities at different levels may substantially reduce postharvest losses, and together with the development of agribusiness provide additional income along the value chain, particularly if diversified production (with more focus on nonstaples) targets newly emerging market opportunities (organic products, supermarkets, etc. Abandoning state interference and policies encouraging investments by the private sector will encourage a shift toward market-oriented agriculture. Strengthened links between research, extension and farmers, possibly by including the private sector, may help implement the required technologies and infrastructure.
- Introducing modern, low-cost farm management systems to improve yields and product quality requires adequate policies. Regulations and procedures associated with seed testing and certification may have to be modernized, and restrictions on the import and use of high-performing seed varieties from other countries be relaxed. Vertical integration and professional value-chain management facilitate quality and safety management at the relevant levels and allow complying with newly emerging standards. Investments in infrastructure and pertinent legislation (e.g. appropriate food safety and biosafety procedures and regulation, revision and modernization of product standards) may be required to improve postharvest management and assure quality control to comply with international standards.
- Import and export policies and trade arrangements have to provide an enabling framework for well-functioning domestic markets. Coherent policies require an integration of AKST and agricultural production in national development strategies and plans to reconcile conflicting views and ambitions with regard to national goals such as national security, food sovereignty

(virtual water trade, etc.), economic growth and development, and quality of life. To strengthen the position of CWANA producers and agrofood businesses in international, globalized markets the negotiating capacity in trade talks may have to be further developed since proactive engagement in trade negotiations and active participation in international programs and initiatives will be required. Reducing the costs and delays associated with border transit procedures and intensifying current efforts to create a low-cost, green corridor that gives improved access to neighboring markets (trade agreements with regional trading partners) may represent further options for making CWANA markets more efficient. Principles of good governance such as representation, transparency, accountability and civil society participation may ensure that social and environmental concerns will be better represented in negotiation processes and resulting agreements.

5.2.4.5 Risk management and property rights

Besides risk-reducing approaches at production level, such as investments in supplemental irrigation facilities or diversification of production, policies have to provide a framework that promotes innovation by reducing associated risks. Well-functioning savings and credit schemes and the development of insurance programs for farmers will encourage farmers to make necessary investments and implement innovative technologies and approaches. Proactive risk management strategies and policies will have to replace the currently prevailing reactive disaster management. This is particularly important in view of the increasing threat of more frequent extreme events caused by climatic change such as droughts, storms and floods, and possible abrupt changes in globalized markets. Improved social safety nets and compensatory policies may also help safeguard the disadvantaged against likely negative effects of structural adjustments and reforms.

Although intellectual property rights are intended to stimulate innovation, enhancing investment in research and access to potentially useful technologies from abroad, they are based on a paradigm of market-led development that contrasts with the traditional approach in agricultural research, which focused on sharing ideas and producing public goods. Currently the issue of IPR is particularly discussed in the domain of plant breeding and biotechnology. The IPR regulatory environment needs to be reshaped to facilitate the generation, dissemination, access to and use of AKST. IPR regulations will have to balance private and communal rights while considering national interests and benefits for local communities. Benefits based on local and traditional knowledge will particularly have to be protected and shared in an equitable manner.

5.2.4.6 Institutional reform and role of government

In CWANA countries where private sector institutions are weak and reform still has far to go, the state retains major responsibilities. Important domains on which government should focus its resources and activities include policy formulation, guidance on legislation and regulation, and provision of essential public services in the areas of seed and plant protection, animal health, border control, food safety, and product standards and certification. Preparing a coherent medium-term sector strategy can form the basis not only for policy formulation but also for ministry input into budget preparation, public investment planning, and specific policies and legislation relating to land use and land reform, trade, taxation, market activity and competition, rural finance, research and extension.

Production targets should be discontinued as a policy instrument and replaced with growth in value addition, household income and export revenue. The efficiency with which essential public services are provided leaves room for improvement in many CWANA countries, and comprehensive modernization of current regulatory practices (including product standards) may be required. There are great opportunities to transfer activities such as seed and livestock breeding to the private sector, and it seems advantageous to allocate more resources to providing information and support to producers and agribusinesses on land privatization and market activity.

The ability of public institutions to reorient their activities is currently constrained by limited awareness of what is appropriate in a market economy, a reluctance to change old approaches, and a limited allocation of human and financial resources for formulating policy. Weak budgetary resources and a significant need to retrain staff and boost output are further constraints.

5.3 Implications of Various Options and Possible Mitigation Measures

Although options to achieve SDGs presented in the preceding sections will contribute to reducing hunger and improving socioeconomic conditions in CWANA, certain options to increase agricultural productivity may have negative environmental effects or be associated with social or economic drawbacks.

The increasing use of pesticides and the related pollution of the ecosystems is a big concern. The trend toward genetically uniform crops increases the potential for serious disaster by eliminating the many different strains of a given crop that farmers previously used. But government policies perpetuate conventional agriculture and discourage farming practices that could make agriculture more sustainable (Chrispeels and Sadava, 2003).

Many modern agricultural practices in the CWANA region are not environmentally sustainable as they have negative aspects (e.g. habitat conversion due to agriculture, soil erosion, and pollution from chemical pesticides and fertilizers). Modern agricultural chemicals have largely contributed to increased crop production, but they also have negative side effects such as groundwater pollution, interference in terrestrial and marine biodiversity, and health hazards to producers and consumers. Therefore, other technical options such as biological control, integrated pest management, integrated crop management, good agricultural practices and organic farming provide great opportunities for making agricultural production more sustainable (Clay, 2004).

New technologies need to be developed and implemented for using and manage limited water resources. These technologies will have to focus, on one side, on quantitative aspects, like increasing water supply and decreasing water demand; on the other hand, conserving water quality will have to receive more attention in the future. AKST in this regard will not only have to concentrate on protecting water resources against pollution from agricultural activities as well as from other sources; it will also have to explore ways to use water of lower quality in agriculture, and to better match the quality of water supplied to its specific use, considering that water of varied quality will be allocated among sectors. Progress in AKST is especially important. Agriculture is by far the biggest consumer of freshwater resources in the region, and progress in AKST will free up water for other sectors, including the environment, which will progressively need more good-quality water.

Measures to balance the effects on natural resources of options fostering agricultural production will have to include public awareness, public education and sufficient regulation. Public awareness and education in this regard should include training farmers in integrated pest management and organic farming practices to reduce the use of chemical pesticides and insecticides, and to improve their knowledge about what fertilizers and nutrients different crops require. Regulations are also required to protect public health and protect natural resources, including soils and water, from degradation.

In the following section, negative externalities related to changes in agricultural production (particularly relating to intensification of production) will be discussed and possible mitigation options presented.

5.3.1 Intensification of crop production

5.3.1.1 Use of agrochemicals

As water is the most restricting factor for agricultural development in the dry CWANA region, emphasis will be placed on using water more efficiently and increasing production per unit of water applied. This will result in more intensive agriculture and will increase the use of agricultural fertilizers and pesticides.

Extending the use of *chemical and organic fertilizers* will result in increasing concentrations of different ions and cations in the soil. This might result in increasing soil salinity, particularly where irrigation water additionally adds minerals to soils, if leaching of salts is insufficient as observed in greenhouse production in the Middle East. Leaching nutrients, on the other hand, may negatively affect water quality with possible effects on human and animal health and eutrophication of water sources. Fertilization according to soil fertility and crop requirements, based on regular soil fertility assessment as well as incremental fertilization and the use of slow-release fertilizers may mitigate such problems. Precision agriculture using both modern tools (such as GIS) and simple techniques (such as fertilizing according to leaf color) may greatly support adequate fertilization (Bahu and Gulati, 2005).

The extensive use of *crop protection products* such as pesticides and herbicides may result in increasing the content of such substances and their nonbiodegradable derivates in soils and water and ultimately in agricultural products, which may compromise food quality and safety. Therefore, the use of crop protection products should be limited wherever possible. Adequate crop rotations and ecological compensation areas may reduce pest, disease and weed pressure. Pesticides and other crop-protection agents should be used according to monitoring and thresholds; IPM and ICM strategies and technologies are available that allow for a minimal, targeted, efficient and still-effective use of crop protection products, although they may have to be adapted to specific local conditions. Organic agriculture, avoiding the use of chemical crop protection agents, not only reduces such risks to a minimum but also has the potential to target growing markets in CWANA and other, mainly industrialized, regions.

Both excessive fertilization and use of crop protection agents may negatively affect biodiversity. Whereas high nutrient loads mainly affect species diversity, organometallic compounds and other chemicals may also affect genetic diversity (Vogt et al., 2007). Since the loss of genetic variation is more difficult to notice than that of species variation, it is important to understand the effects that different pollutants have on ecosystems and on species and their genes.

Monitoring environmental indicators and parameters relating to possible pollution of natural resources by organic fertilizers and agrochemicals will be important for maintaining a healthy resource base. Food quality and safety monitoring and control in accordance with pertinent legislation and regulations that may need to be developed will be necessary to prevent health problems and to comply with international standards.

5.3.1.2 Mechanization

Extensive use of mechanization may result in losing soil organic matter and thus soil fertility. It can also reduce macropore spaces in soils and thus decrease soil aeration. Mechanization may compact the soil and tillage hardpan may form, which will reduce the permeability of subsoils for water and roots. Furthermore, frequent and thorough working of the soil may negatively affect biodiversity. Conservation tillage options and adequate crop rotations may overcome such negative effects of mechanization.

Promoting mechanization may also have socioeconomic consequences. Depending on machinery and maintaining it with fuel and spare parts may increase the risk of debt, particularly if framework conditions promote over mechanization. Extension services therefore will need to support farmers in assessing the cost efficiency of investment in mechanization and relate it to their capacities, and savings and credit systems need to allow for pertinent investments. Since machinery is mostly designed for use by men, women might be left with an increased burden of tedious nonmechanized work. To counteract such increased gender imbalances, mechanization will have to consider the feminization of agriculture and design implements that are suitable for women.

5.3.1.3 Reduction in diversity

Intensification of agricultural production in recent decades has generally been associated with simplification of agricultural systems (Haykazyan and Pretty, 2006). In addition to the negative effects of mechanization, biodiversity loss and a declining diversity in agriculture itself (Haykazyan and Pretty, 2006) have resulted from pesticide and fertilizer use, expansion of cropped surfaces, land degradation and the use of a narrow range of high-yielding crop varieties based on conventional breeding or biotechnology. To counteract these trends, appropriate legislation is required that fosters ICM practices and promotes the provision of ecosystem services through agriculture.

However, awareness about the importance of biodiversity is generally low in CWANA, particularly among farmers. Initiatives to conserve biodiversity have so far mainly been successful only if tangible benefits were perceived. It is therefore necessary to raise awareness about the benefits of conserving biodiversity such as reduced pest and disease pressure in diversified systems and resilience of diverse agricultural systems and landscapes to shocks and stresses. Emerging markets for biodiversity-based products may offer economic incentives to land users. Participatory approaches and shared management, possibly including payments or other incentives for ecosystem services, may represent acceptable approaches to encourage the adoption of conservation practices. In situ and ex situ conservation of biodiversity, participatory decentralized breeding approaches, and integration of local, traditional knowledge and experiences in AKST may further contribute to conserving biodiversity in intensified production systems.

5.3.2 Intensification of livestock production

Interaction between livestock and the environment has been a subject of global debate in recent years, focusing on negative aspects such as global warming with little attention being paid to the positive attributes. It is not disputed that livestock contribute to greenhouse gas and other atmospheric emissions, which contribute to climate change; it has been reported that livestock account for 35–40% of all anthropogenic emissions of methane (Steinfeld et al., 2006). Livestock also contribute to carbon dioxide emissions through basic metabolism and respiration. These negative factors of livestock rearing may be reduced considerably, and there are also many positive elements of livestock–environment interactions that should not be overlooked.

5.3.2.1 Zoonoses and other diseases

The perpetuation and transmission of a group of diseases shared between humans and other vertebrates that act as reservoirs of infection is an important hazard for human health that arises from livestock rearing. These diseases are popularly known as zoonoses. Some like trichinosis and salmonellosis are exclusively or partially food borne through meat, milk or eggs (Majok and Schwabe, 1996; Payne and Wilson, 1999). A second group that is emerging is thought to be perpetuated through human–animal interactions, such as avian influenza (bird flu). The current challenge is that there are no known technologies or management practices acceptable to farming communities to deal with these groups of infections. Zoonoses are among the most complicated human diseases from an epidemiological standpoint and therefore controlling them requires an extremely good understanding. This knowledge first has to be developed in most of the CWANA region. Important methods for dealing with this group of infections are to promote surveillance and reporting by collaborating with medical and public health experts, and to conduct education and awareness campaigns about how people are exposed through animals and their products and the risks of such infections. Good hygiene practices in processing foods of animal origin are further safeguards for insuring food safety for human consumption. These practices will have to be improved as technologies become more advanced with the acquisition of new scientific knowledge.

5.3.2.2 Residues

Health risks also occur as a result of livestock management practices. Currently, human hazards from chemical residues in foods of animal origin may not be an issue of major proportion in

CWANA because the costs of such products are too expensive for most resource-poor small-scale farmers. Mineral supplements such as sulfur and phosphorus, which ruminants must have to utilize nitrogen, as yet have little if any market in CWANA. The use of anabolic steroids and other compounds used as feed additives for cattle to promote faster growth, as well as elevation of natural levels of somatotropins in cattle, pigs, poultry and sheep are not yet widespread. However, such hazards may become of major concern in the near future as chemicals, medicines and agricultural by-products for feeding livestock become less expensive and more widely used (Smith et al., 2005), and as awareness rises about health risks with foods of animal origin. The challenge, therefore, is to design and operate organized multilevel systems for detecting and assessing the environmental hazards and monitoring environmental quality (Schwabe, 1984). Possible technological approaches for consideration involve the following:

- Evolve appropriate mechanisms for recognizing and detecting new hazards through their effects upon animals.
- Develop protocols for animal testing of potential hazardous substances.
- Use specific health indicators to monitor the environment.

Assays for toxicity and safety of manufactured chemical substances of diverse nature—drugs, food additives, pesticides, and other agricultural and industrial chemicals—that are currently used to assess human risk will probably have to be complemented by a range of tests with appropriate animal species (Newberne, 1980; Squire, 1981) to detect not only acute toxicities but also mutagenic, carcinogenic, teratogenic or other chronic effects.

Dealing with issues of residues of growth hormones, antibiotics, feed additives, heavy metals, etc., in livestock products is, however, often problematic because farmers want their animals to grow fast to reach market weight quickly. Nevertheless, health risks due to residues are a concern and have therefore to be considered.

5.3.2.3 Manure and waste management

Besides the close interaction between livestock and humans and the consumption of animal products, direct human health effects of pollution from rearing livestock pose an additional threat to human health and the environment, particularly in intensified production systems. High levels of nitrates in water may lead to disease such as the blue baby syndrome (Pretty and Conway, 1988). More importantly, manure, through contaminated water or fresh produce, can carry a range of serious human pathogens, with high incidence of morbidity and mortality, particularly in babies and young children. These pathogens, often asymptomatic in livestock, vary from bacterial pathogens such as *E. coli, Campylobacter, Salmonella,* and *Leptospira* spp., and protozoan agents (*Cryptosporidium*) to viruses such as the hepatitis A virus (World Bank, 2005).

The potential threats of pollution to the environment and human health will have to be watched cautiously. Removing policy distortions that promote artificial economies of scale in livestock production, developing approaches to let resource-poor producers capitalize from the benefits of increased livestock production, and regulating environmental and public health concerns will represent important challenges for CWANA decision makers. Technological options for improved handling and storage of animal waste exist and may be promoted by adding value to these wastes by using them in biogas digesters for energy production and as fertilizers. Area wide integration of specialized crop and livestock production may help to reinstall the link between livestock and crop production, not only on the farm but on a regional scale. By fostering collaboration between specialized livestock operations and crop farmers, animal waste may be recycled in an environmentally and economically beneficial way (Menzi et al., 2003).

5.3.3 Fisheries and aquaculture

About 200 types of diseases are known that can be transferred from foods to humans (FAO, 2000). Fish products can be a source of disease due to general food habits, rate of consumption, type of product and species of fish. Therefore, fish producers have established and applied a system called Hazard Analysis & Critical Control Points to eliminate or reduce the adverse health effects of fish products.

Several organic substances such as dioxin and inorganic substances such as cadmium and mercury can affect fish quality. Their deleterious effects increase if they exceed the maximum allowable limits and if they occur in closed seas and rivers (FAO, 2004). Even if these substances occur in food fishes in low quantity, their incidence may be of concern for people who eat fish daily and for pregnant women, infants and children who eat large quantities of fatty fishes.

The safety of aquaculture products is important as production from aquaculture has increased and become available to more people. Antibiotics are frequently used in aquaculture to prevent or treat diseases. Therefore, responsible limiting of the use of antibiotics is important for sustainability aquaculture and for safety of fish products. Responsible use implies determining the maximum residue level of these antibiotics and ensuring that these levels are not exceeded.

Food safety in fisheries is important and has been endorsed by international agreements. The FAO Code of Conduct for Responsible Fisheries clearly requests countries to develop their fisheries in a way that does not result in environmental degradation or health problems for people.

5.3.4 Water management

5.3.4.1 Conflict over water resources

As a result of increasing water demands for agriculture, depletion of water sources and conflicts over them are expected to increase in CWANA. These conflicts may arise at various levels such as among sectors using water or among different user groups. Regional conflicts between countries over shared water resources will probably intensify; conflicts over surface and groundwater sources may accelerate and add to existing tensions and conflicts in the region. Possible conflict areas might include the Tigris, Euphrates, Jordan, Indus and Nile river basins. Conflicts over groundwater sources might include the countries of North Africa and the Middle East. Mitigation of such conflict potential may include demand management in different facets, bi- and multilateral negotiations and agreements, or an increase in virtual water trade—e.g. by producing and exporting high-value crops with low water requirements and importing water-intensive crops from a subsidized world market (Allan, 2002). Negotiations should respect the Helsinki rules and guidelines (International Law Association, 1967) and foster their implementation to avoid conflict; regional parties need to cooperate to formulate regional solutions for water shortages.

Nearly all water resources in the region are being used. Therefore, water shortages are expected to result in more pressure on the agricultural sector to divert water from agriculture to other uses such as industrial and domestic sectors. This will result in conflict among sectors and internal socioeconomic and political tensions. Each country of the region will need to address these conflicts specifically, but participation of all concerned stakeholders in pertinent discussions and negotiations will greatly facilitate solutions that allow for optimized economic and social welfare derived from water resources, their equitable allocation and their environmental sustainability. The systems of water rights and water allocation will have to be adapted in all countries of the region, addressing water allocation among the sectors and respecting historical water rights of the different users. The promotion of water-user groups (or water-user associations) who jointly manage and organize water distribution may improve the efficiency of water use and the distribution and management of water resources while at the same time empowering local populations and relieving public institutions. If all concerned stakeholders can participate in such associations internal conflicts over water distribution and water allocation may be mitigated.

Improving on-farm water management and the efficiency of water distribution can reduce return flows and possibly reduce recharge of certain groundwater aquifers. Since existing resources are fully used in most countries of the region, reducing return flows and improving the efficiency of water use at the upstream end of any river basin might result in reducing water availability for downstream users, thereby increasing conflicts over water resources. For example, when surface water systems are replaced by pressurized irrigation systems or if surface irrigation efficiency is improved (e.g. using surge irrigation), tail water runoff will reduce. Upstream users will increase their irrigated areas as a result of water savings, but downstream users might be adversely affected because return flows to them are reduced. Again, following the IWRM principles, having all concerned stakeholders participate in planning and implementing significant changes in water management may mitigate such conflict potential.

5.3.4.2 Depletion and development of water resources

Another effect of improved irrigation efficiency, particularly on highly permeable soils, is reduced seepage to unconfined aquifers, which may reduce the safe yield of such aquifers and possibly decrease the amount of water available from them. Together with increasing agricultural and domestic demands this situation may additionally deplete renewable and nonrenewable water sources. Many countries in the region—Saudi Arabia, Jordan and Libya—have been using nonrenewable sources. It is expected that these sources will be depleted in the future, and new water sources will have to be found. In other areas, the renewable water sources have been depleted beyond their safe yield capacities and thus their water quality has been deteriorating. An example is Gaza Strip, where groundwater resources have been used beyond their natural recharge capacity. Seawater intrusion and intrusion from brackish groundwater aquifers have now deteriorated these resources. Besides enhancing natural recharge, such as through appropriate land management, artificial recharge of groundwater aquifers may reduce problems associated with decreased groundwater availability.

The development of new water resources, however, may entail deleterious side effects. Creating new (particularly large) reservoirs may not only flood fertile valley bottoms but dislocate the local population and destroy property, habitats and cultural heritage. Having local communities participate in decision making, establishing smaller-size structures or reducing demand may avoid the necessity for large dams and reservoirs.

5.3.4.3 Use of unconventional water

As water resources are limited in the region, the use of marginal water such as brackish and treated wastewater will increase. However, the use of unconventional water resources may be associated with certain problems. Using treated wastewater in agriculture might entail health hazards and create water-quality problems that will have to be addressed. Contaminating crops with harmful microorganisms such as *Salmonella* in lettuce and onion or *E. coli* in sprouted seed are potential risks associated with using wastewater for irrigation (Jones et al., 2006), and nematodes and pathogens in soils occur more frequently. Using marginal water such as drainage, saline or brackish water, and wastewater may also affect soil and water quality negatively. Accumulation of salts, heavy metals and other substances in soils and water will have to be prevented by establishing and enforcing pertinent legislation and control. Regulations regarding wastewater treatment and reuse will particularly have to cover the responsibility of water polluters in treating their wastewater to a standard acceptable for safe use, as in agriculture, or for disposal in the environment. Increased awareness among farmers, water users and crop consumers will be required to address issues related to health and water-quality aspects.

5.4 Uncertainties

The preceding sections of this chapter have demonstrated that there is a whole range of technological, institutional and policy options through which AKST can contribute toward achieving SDGs. If appropriate countermeasures and precautions are considered, even possibly associated negative implications of these options may be dealt with and mitigated.

The future, however, bears uncertainties related to environmental framework conditions. Important changes and developments that are difficult or even impossible to foresee may affect agriculture and the role and effect of AKST considerably. Uncertainties are arising in various domains such as the geopolitical situation, global markets and trade (international trade regimes for agricultural inputs and products), supply and demand for agricultural products (e.g. biofuel vs. food and related effects on prices and the environment), price developments for inputs (e.g. energy prices) and outputs, climatic changes and unstable weather patterns (with their effect on resource quality and availability), the ability to tackle human, animal and plant diseases, and acceptance of genetically modified foods. Possible effects of some of the major uncertainties facing agriculture and AKST are briefly discussed in the following section.

Global markets and trade. **Weather-related production shocks, energy price trends, investment in biofuel capacity, economic growth prospects and future agricultural policy developments are among the main uncertainties affecting the prospects for world agricultural markets (OECD-FAO, 2006). A major uncertainty is the outcome of the Doha Development Agenda of multilateral trade negotiations. If trade barriers and support for agricultural production are substantially lowered, world prices for a number of agricultural commodities as well as trade may rise considerably. Outside the Doha negotiations, however, bilateral or regional free trade agreements may increase trade in agricultural products between members.**

Increased trade opportunities coupled with higher product prices may change the focus of agricultural production and related AKST toward more export-oriented strategies. Whereas producers might benefit from such developments, poor consumers in urban areas particularly might suffer from higher food prices. Emergence of new markets for biofuels, carbon trading and biodiversity preservation also open new opportunities yet to be tapped (World Bank, 2007).

Domestic policy changes in important producer and export countries such as the United States represent further uncertainties. The prospects for world agricultural markets are highly dependent on economic developments in Brazil, China and India, three of the world's agricultural giants. Outbreaks of animal diseases such as BSE or avian influenza may greatly influence demand and have significant consequences for producers. Shifts in demand from an affected commodity to another may occur briskly, and markets of affected countries may close up. Animal diseases may thus cause major disruptions in the meat sector, which will be further transmitted to feed markets (OECD-FAO, 2006).

Energy prices. **Higher energy prices, as for crude oil directly impinge on agricultural production costs. Energy is used directly to operate machinery, and indirectly through such inputs as fertilizers and pesticides, the production of which is particularly energy demanding (World Bank, 2007). Increasing energy prices would thus raise production costs, which would be translated into higher commodity prices both regionally and internationally. As the share of energy in production costs is substantially higher for crops than for livestock, crop production is particularly affected by changing energy prices (OECD-FAO, 2006). However, since intensive livestock production is strongly based on cereals and oilseed meal, livestock products will be affected as well, although to a lesser extent. Higher energy prices are therefore expected to reduce trade volumes of most commodities, particularly crops, all the more so because transport cost will also increase. On the other hand, a further increase in crude oil prices may promote a shift towards bioenergy production.**

Bioenergy. **Developments in bioenergy production represent a major uncertainty for agricultural production and markets, and for achieving SDGs in general. High energy prices combined with increased biofuel production from food crops could lead to large increases in food crop prices by affecting both supply and demand (World Bank, 2007). Commodity prices for crops such as maize, wheat, oilseed and sugar may rise drastically (by 30–75%) (World Bank, 2007), and competition between food and feed uses and nonfood uses for particular crop sectors may result in major production and market changes (OECD-FAO, 2006). Not only would bioenergy crops be affected; through cross-commodity influence, production and availability of traditional foods and feeds might decrease. Furthermore, increased bioenergy production might accelerate land conversion**

from forest to agricultural use or from extensive to intensive production, which may—together with the escalating demand for livestock products—considerably affect the environment negatively through deforestation and degradation of land and water resources.

It is important to note that the currently observed boom in producing bioenergy is mostly based on public support and encouragement (OECD-FAO, 2006). Such support may create market distortions that need to be better understood before pertinent policies are put in place. However, the economics of bioenergy, and particularly its positive and negative externalities, are not yet well understood and depend critically on local circumstances (Avato, 2007). These knowledge gaps related to increased bioenergy production call for investment in AKST research and development to produce more sustainable technologies that are adapted to smallholder farming systems. Research needs to develop second-generation biofuels that rely on agricultural and timber wastes instead of food crops, thus reducing the pressure on food crop prices and possibly contributing to the supply of more environmentally friendly supplies of biofuels (World Bank, 2007).

Climate change. Global warming is one of the areas of greatest uncertainty for agriculture (World Bank, 2007). So far, not all effects of climate change on agricultural production and yields have been included in crop–climate models. Nonlinearity of yield response to temperature above threshold levels can result in high losses with moderate temperature increases that are not yet considered. The combined effect of higher average temperatures plus variability of temperature and precipitation, more frequent and intense droughts and floods, and reduced availability of water for irrigation is likely to affect yields negatively, even globally, and can be devastating for agriculture in many tropical regions. Assumptions about the magnitude of the effect of carbon fertilization are still debated although they are critical for predicting whether crop yields will increase under elevated CO_2 concentrations. Climate change is also increasing production risks in many farming systems, reducing the ability of farmers and rural societies to manage risks on their own.

Uncertainty regarding what climatic changes to expect is even higher in view of increasing evidence that these changes are happening at a pace faster than that until recently foreseen (World Bank, 2007). Proactive strategies and research are therefore crucial to face these uncertainties.

Genetically modified organisms (GMOs). Worldwide, many people are eating genetically modified foods with no adverse affects on human health having been reported in peer-reviewed scientific literature. However, there could still be long-term effects on human health that have not yet been detected (genetically modified foods have been available for fewer than ten years). Although many field trials have been held, and in some parts of the world there has been large-scale commercial planting of genetically modified crops, work done has been insufficient to fully assess environmental effects, especially in the biodiversity-rich tropics (OECD, 2000). Modern biotechnology has opened up new avenues and opportunities in a wide range of sectors, from agriculture to pharmaceutical production. Nevertheless, the scale of the global debate on GMOs is unprecedented. This debate, which is intensive and at times emotionally charged, has polarized scientists, food producers, consumers and public interest groups as well as governments and policy makers (FAO, 2001). Today, it is not clear to what extent the incredibly rapid expansion of genetically modified crop production and use in animal (particularly fish) production will continue, particularly in the developing world. Due to the intensity of the debate over GMOs, new discoveries may have massive effects, particularly on the demand side. In addition, neglected investment of GMO developers in traits and crops that will benefit the poor and weak regulatory capacity and systems fuel public distrust and ignite opposition of various interest groups to widespread GMO use (World Bank, 2007).

People in general are directly interested in technological developments, yet obstacles to their participating in making decisions must be acknowledged and overcome. The public has not been adequately informed about applying gene technology to food production and the potential consequences on consumer health or the environment. With the confusing array of claims, counterclaims, scientific disagreement and misrepresentation of research that is present in the media, the public is losing faith in scientists and government. Widely communicated, accurate and objective assessments of the benefits and risks associated with genetic technologies should involve all stakeholders. Experts have the ethical obligation to be proactive and to communicate in terms that the lay person can understand. More opportunities are needed that enable the exchange of information among scientists, corporate representatives, policy makers and the public at large. Including members of the public on advisory committees set up to formulate laws, regulations and policies would help ensure that their perspectives are fairly represented (FAO, 2001).

5.4.1 Investment in AKST

Investments in AKST have hugely accelerated growth and reduced poverty in much of the developing world. However, although agricultural productivity improvements have been closely linked to investments in AKST, market failures have led to serious underinvestment. Trade subsidies and national policies that reduce incentives to farmers in developing countries are a disincentive to public and private investment in AKST (World Bank, 2007).

Increasing public and private investment in AKST and strengthening institutions and partnerships with the private sector, farmers and civil society are now essential to bridge the knowledge divides, strengthen user demand for AKST, increase competitiveness, and ensure that the poor participate and benefit. These investments will be even more important in the future, with rapidly changing markets, growing resource scarcity, and greater uncertainty from multiple threats. Ways to increase investments in AKST exist, such as by forming coalitions of producer interests around particular commodities or value chains, to lobby for more public funding and for producers to cofinance AKST. In addition, institutional reforms will be needed to make investing in public AKST more attractive and to make funding more transparent and open to a wider range of research providers in universities, civil society and the private sector (World Bank, 2007).

5.5 Ways Forward

A whole range of technological, institutional and policy options exist to overcome the major challenges for attaining sustainable development goals in the CWANA region. Although the options presented can positively affect achieving sustainable development goals, some might at first sight be associated with negative externalities, particularly with regard to the environment and natural resources. However, provided that appropriate precautions and countermeasures are implemented, most of these implications can be mitigated.

Technological options alone generally cannot bring about the hoped-for changes. Framework conditions have to be favorable for technological achievements to be successfully implemented. Economic aspects, institutional arrangements, and political decisions and regulations have to form a coherent framework in which AKST and its achievements can flourish. Using natural resources, employing research, training and extension methods, and educating the public, making it aware and getting its participation are all required and must be balanced to achieve optimal results.

Many of the options presented are valid for most countries in the region. However, these options will have to be adapted to the specific environments targeted. Furthermore, the options will receive different priorities in the various CWANA countries. Each country will need to develop strategic plans to select and prioritize policies according to its local circumstances and needs.