IAASTD GLOBAL CHAPTER 6
OPTIONS TO ENHANCE THE IMPACT OF AKST ON THE DEVELOPMENT AND SUSTAINABLITY GOALS

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Key Messages

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Smarter and more targeted application of existing best practice AKST continues to be critical to achieving the IAASTD goals. It is essential to draw on competences from and build on developments in a wide range of sectors to have the maximum impact on achieving the goals. The greatest scope for improving livelihood and equity exists in small-scale diversified production systems.

The challenges of meeting the IAASTD goals [in the future] are becoming increasingly complex, so AKST must be integrated with place-based and context relevant factors to address the multiple functions of agricultural productivity and will require broad-based comprehensive solutions that increase productivity, protect natural resources and the functional base of agriculture, as well as minimize agriculture's negative impact on the environment. Furthermore, the diversity of farmer needs and potentials and the increasing complexity of stresses under which they operate, require the development of multiple options.

Advances in AKST, such as through genomics, nanotechnology, remote sensing, precision agriculture, information communication technologies, will transform our approaches in addressing IAASTD goals, but will need to be inclusive of a wide variety of approaches in order to meet sustainability and development goals. There will be new genotypes of crops, livestock, fish, and trees to facilitate adaptation to a wider range of habitats and biotic and abiotic conditions. This will bring new yield levels, produce non-traditional products or traditional products from non-traditional sources, and complement new production systems. New approaches for crop management and farming systems will develop alongside breakthroughs in AKST. The widespread application and impact of these breakthroughs will depend on resolving concerns of access, affordability, relevance, bio-safety, and the policies (investment and incentive systems) adopted by individual countries. Emerging knowledge of agroecological processes and synergies, and the application of resultant technologies, will play a crucial role in future AKST response to the challenges of hunger, productivity, and environmental protection. Expanding the habitat range of existing plants, animals and microorganisms of agricultural value could decrease ecosystem services from environments that help recycle and remediate the impacts of agriculture, undermining projected yield gains. Current and future advances in agroecology, however, may offer the potential to capture productivity benefits while simultaneously providing critical ecosystem services, including optimal soil and water quality, carbon sequestration, and biodiversity. Ecological approaches to food production also have the potential to address inequities created by industrial agriculture.

Energy resources are both a challenge and an opportunity for agriculture, particularly in the face of rising and volatile energy prices and climate change. New AKST will be needed to reduce the reliance of agriculture and the food chain on fossil fuels for agro-chemicals, machinery, transport, and distribution. Emerging research on energy efficiency and alternative energy sources for agriculture will have multiple benefits for sustainability. Targeting existing bioenergy technologies towards poor, rural areas and developing new bioenergy technologies can contribute to achieving the IAASTD goals. Current bioelectricity technologies such as cogeneration and biomass digesters, are significantly underexploited, and can help increasing access to modern energy services, especially in rural, off-grid areas. New or yet to emerge, cellulosic ethanol and gasification technologies hold promise to mitigate some of the most disastrous economic, social, and environmental costs that are posed by current liquid biofuels technologies. However, it is not clear when these technologies will become commercially available.

Reconfiguration of agricultural systems, including integration of ecological concepts, and new AKST are needed to address emerging disease threats. The number of emerging plant, animal, and human diseases will increase in future. Multiple drivers, such as climate change, intensification of crop and livestock systems, and expansion of international trade will accelerate the emergence process. The increase in disease emergence will challenge sustainable development and economic growth, and it will impact both high- and low-income countries.

AKST can play a proactive role in mitigating climate-related production risks and adapting to climate change. Climate change influences and is influenced by agricultural systems. The negative impacts of climate variability and projected climate change will predominately occur in low-income countries. AKST can be harnessed to reduce GHG emissions from agriculture and to increase carbon sinks.

Participatory approaches and multicriteria analysis are necessary to prevent and resolve problems in conflict areas, such as transboundary basins. Conflict over natural resources and shared environments will intensify [in future] as a result of population growth, water scarcity, environmental degradation, climate change, refugee flows, and increasing inequalities

6.1 Options for improving Agricultural Systems in an Environmentally and Socially Sustainable Manner

6.1.1 Challenge: enhance plant breeding and crop production to develop varieties that will overcome expected productivity declines in an environmentally and socially sustainable manner.

6.1.1.1 Conventional plant breeding.

Option: Ensure that existing specialist knowledge in plant breeding and access to the gene pool of wild (landraces) and domesticated varieties is not lost so that future farmers can access genotypes for tomorrow's changing plant production needs.

Assessment: Modern, conventional and participatory plant breeding approaches play a significant role in the development of new crop varieties. It will be more important in the future, because of physical and market diversification. There is a need for new varieties of crops with high productivity in: currently marginal or unfavorable environments; resource limited farming systems; Intensive land and resource use systems; and changing conditions as caused by global warming; and bioenergy (See bioenergy 6.2.5).

Option: Improve productivity by ensuring access to locally produced high quality seeds and farmer to farmer exchanges, and encouraging local knowledge and control of intellectual property.

Assessment: Plant breeding is facilitating the creation of new genotypes with higher yield potentials in a greater range of environments. But it is not a solution for every circumstance, and may have limited profitability in unfavorable conditions. Plant breeding activities differ between countries depending on seed delivery systems. In developing countries, public plant breeding institutions are common but globalization and privatization threaten these institutions (Maredia, 2001; Thomas, 2005). Public investment in genetic improvement needs to be augmented by research units composed of local farming communities.

Local seed production and farmer-to-farmer seed exchange that have been successful practices in many countries are part of a sustainable strategy to eliminate hunger and poverty. Increasing corporate control of food production, such as corporations owning seed companies and technologies, can result in rising costs for farmers and may even accelerate debt spirals and land displacement. Women who are in charge for food seed production and storage in most farming communities are most affected by the increasing influence of seed companies (Pionetti, 2005).

Provided that steps are taken to maintain local ownership and control of crop varieties, plant breeding remains a viable option for meeting ISAADT goals. An essential early step may be to appoint advisers to farmer NGO's, guiding their investments in local plant improvement.

6.1.1.2 Plant breeding assisted by genomics and recombinant DNA (rDNA) techniques

Option: Use of genomics to aid conventional plant breeding. Whole genome analysis coupled with molecular techniques can accelerate the breeding process, because the few individuals with precisely the combination of chromosomes and genes desired can be rapidly screened among progeny.

Assessment: Prior to the era of whole genome sequencing, plants were selected based on observed traits. These traits could be caused by a single gene (rarely) or by the contribution of multiple genes (most often). Combining plants with different and desirable traits can be slow because the genes for the traits are located in many different places in the genome and may segregate separately during breeding. Plant breeding augmented by molecular screening is likely to yield rapid advances in existing varieties. This process, however, is limited to the gene pool in interbreeding plants, and there may be a limit to the range of traits available within species to existing commercial varieties and wild relatives (Brush and Meng, 1998). This of course makes the preservation and expansion of both in situ (conservation areas) and ex situ (e.g., Future Harvest Centres) conservation of wild plants and crop ancestors extremely important for ongoing success (also see preceding section).

This approach to crop improvement is expected to be easily integrated into most regulatory frameworks and meet little or no market resistance. This is because it does not involve producing plants using rDNA techniques. Thus, they are not regulated articles or the subject of international treaties such as the Cartagena Protocol on Biosafety. Varieties that are developed in this fashion can be covered by many existing intellectual property rights mechanisms (such as TRIPS (Bender, 2006) and UPOV) and would be relatively easy for farmers to experiment with under “farmers’ priviledge” provided that suitable sui generis systems are in place (Sechley and Schroeder, 2002). Still, care needs to be taken over introducing non-native species as crop plants, as they could become invasive or problem weeds, or cross pollinate with wild plants in the area threatening biodiversity.

Option: Transgenic (GM) plants. Recombinant DNA techniques allow rapid introduction of new traits determined by genes that are either outside the normal gene pool of the species or for which the large number of genes and their controls would be very difficult to combine through breeding. Extensive experimentation on extending tolerance to both biotic (e.g. pests) and abiotic (e.g. water stress) traits is currently underway.

Assessment. The success of transgenics at producing stable varieties with predictable qualities is still difficult to assess because of their limited geographic range and time in the field. Extrapolation of their potential is limited by the currently small number of environments in which they are grown at large scale, mainly North America and Argentina, and the small number of traits that have been tested in under two decades of commercialization (James, 2007; Pretty, 2001). Those traits are pest and herbicide tolerance, for which yield claims, adaptability to other ecosystems and other environmental benefits, are contested (Pretty, 2001; Villar et al., 2007), leaving a large uncertainty about how this approach will make lasting productivity gains. The more we learn about what genes control important traits, the more genomics also teaches us about the influence of the environment and genetic context on controlling genes (Kroymann and Mitchell-Olds, 2005; MacMillan et al., 2006) and the complexity of achieving consistent, sustainable genetic improvements. This has lead to sobering qualifications on the rate at which genomics and attendant biotechnologies will produce substantial changes in global food yields (Sinclair et al., 2004).

Adapting any type of plant (whether transgenic or conventionally bred) to new environments also has the potential to convert them into weeds or other threats to food and materials production. Through gene flow, wild relatives and other crops may extend their climate tolerances and thus further threaten sustainable production. An added complication is that these new weeds may further undermine in situ conservation efforts. The emergence of a new agricultural or environmental weed species can also be a decade (or longer) scale event. For example, it can take hundreds of years for long-lived tree species to achieve populations large enough to reveal their invasive qualities (Wolfenbarger and Phifer, 2000).

In addition to environmental concerns, transgenic technologies have been slow to be taken up (Table 6.3.2) worldwide and so far they are meeting significant regulatory and market challenges, particularly in Europe (Davies and Newton 2006). Taken together, genetic modification using rDNA is less likely to produce new varieties of substantial value. The existing GM varieties in commercial production, such as herbicide tolerant soya bean and insect resistant cotton and maize, will continue in use but will be obsolete by 2050.

6.1.2 Livestock production

6.1.2.1 Challenge: Improving performance of livestock systems.

Option: Increase livestock production in small farm households where livestock often play a vital role to generate additional income and employment. Target action to provide adequate technology and affordable inputs to small livestock keepers.

Assessment: Livestock production in small farm households is to be seen in the context of the farm's entire economic situation. With regard to poverty reduction and the Millennium Development Goals, livestock generates or has the potential to generate in many small households additional income and employment (LivestockNet, 2006; ILRI, 2003). Many smallholders do keep only few livestock mainly chicken or small ruminants or even do not keep livestock at all. The fact that these are farm households and some basic fodder and feed resources often are available on farm makes this group an ideal target to introduce livestock or improve present systems (PPLPI, 2001). Although output per farm may be seen as small, the sheer number of this type of households makes them also in future a force to reckon. Dairying in India (Doornbos et al., 1990; Kurup, 2000) or piggery in Vietnam (FAO, 2006) or backyard poultry in Africa (Guye, 2000); there are many examples where small households contribute to the supply of an entire country or region. Adding or intensifying the livestock component in small farms also increases the availability of farm yard manure which allows these households harvesting increased yields from their crops grown. In this way, increased focus will be put on mixed crop-livestock systems for a sustainable farming (Steinfeld et al., 1997).

Option: Increase production through enhanced productivity of livestock in extensive systems of pastoral and semi-pastoral communities where livestock are vital to their livelihood. Target action to provide planned and well-balanced access to grazing and water-endowed areas to preserve scarce and disperse resources in nomadic or semi-nomadic livestock systems.
Assessment: Pastoral and semi-pastoral communities face increasingly the problem that pasture land can not be further extended, e.g. deforestation to gain new grazing areas is no longer an accepted practice (Steinfeld et al., 2006). In some areas pasture land is even decreasing as it is converted into crop land, often resulting in land use conflicts (ECAPAPA, 2005). Where pasture areas remain more or less stable, productivity of land and ultimately of livestock is threatened due to overstocking and subsequently overgrazing. With this rather gloomy picture, pastoral and semi-pastoral communities have to find ways to increase their output first of all through improved productivity. Better animal health and condition through improved access to veterinary services, including the establishment of systems of community-based animal health workers (Leonard et al., 2003), and seasonal feeding of conserved fodder and feeds are thereby in the forefront. With regard to grazing, more systematic rotational grazing and fencing may be considered, although the latter is not everywhere accepted and possible, in particular in areas with communal grazing land (Republic of Namibia, 2002). Furthermore, to increase offtake rates is also a socio-economic problem there where livestock is mainly kept as “bank on hoof”. All this underlines, that traditional pastoral societies are driven by complex interactions and feedbacks that involve a mix of values including biological, social, cultural, religious, ritual and conflict issues (Ørskov and Viglizzo, 1995) as well as conservation issues with regard to farm animal genetic resources (Bayer et al., 2003), while at the same time the projected output from these pastoral systems remains limited.

Option: Improve intensive livestock production systems. Target action to ensure appropriate location of intensive livestock units away from highly populated areas, and the application of technological and management practices to minimize water, soil and air contamination.
Assessment: Although there are spectacular increases concerning their outputs, intensive livestock production systems are increasingly seen in relation to environmental externalities (de Haan et al., 1997) , including contamination of air and water resources (FAO, 2006). Locations of future intensive systems must be assessed, thereby also taking the whole livestock food value chain into consideration, starting from the production of fodder and

animal feeds up to processing and marketing of livestock products. Concerning more comprehensive links between fodder base and production units there will be increased focus on area-wide crop livestock integration (Steinfeld et al., 1997). As market-related, cross-regional functions such as assembly, transport, processing and distribution can be cause of other externalities, they must be assessed as an integrated whole. Intensive systems are prone to disease and animals can spread zoonotic diseases like tuberculosis or bird flu that can affect humans (LEAD, 2000).

Option: For all types of livestock production systems, focus on increased sustainability. Orient land-use strategies and tactics for sustainable agriculture and livestock systems to preserve the soil and forage base through a number of measures such as the promotion of conservation tilling practices, crop and pasture rotation, suitable stocking rates, biological fixation of nitrogen, etc.

Assessment: Sustainability of the various livestock systems is threatened in different ways. While for small households their limited resource base in form of land, labor and capital may put a risk to sustainable livestock production (Bachmann, 2004), there are mainly environmental concerns threatening the extensive pastoral and semi-pastoral systems as well as the large intensive livestock production units (Steinfeld et al., 2006). Livestock systems that utilize lower levels of fossil energy and inputs are a healthier alternative for both, developed and developing countries (Harper, 1974). In such cases, the technological focus must be put more on the application of management rather than on the input technology (ILRI, 2003). Land-use strategies involving participatory approaches are necessary in order to sustain livestock systems and to avoid conflicts (ECAPAPA, 2005).

6.1.2.2 Challenge: Improving livestock breeding.

Option: Closely follow developments using genomics as genomic applications in agriculture contribute to more efficient use of resources and can result in higher productivity.

Assessment: So far, the impact of genomics in livestock agriculture can be gleaned from the development and use of transgenic animals such as chickens and cattle to produce pharmaceutical or therapeutic proteins in eggs and milk (Gluck, 2000). Its uses in diagnostics and vaccine development for animal diseases, and in feed production and formulation (Machuka, 2004) may further boost the livestock industry, although the competition from alternative sources will probably be strong (Ma et al., 2005; Min Chen, 2005; Twyman et al., 2003). Breeding livestock with enhanced growth characteristics is also made possible with genomics because many vaccines and growth hormones are open to recombinant DNA manipulations (McKeever and Rege, 1999). However, all these new technologies do create safety risks and may not always increase sustainable production. Hence, applications should be thoroughly evaluated to ensure that they do not also undermine IAASTD goals.

Option: Critically follow and assess further development of transgenic livestock.
Assessment: There are currently no transgenic livestock animals in commercial production and none likely in the short term (van Eenennaam, 2006). Over the next 10-50 years there is some potential for development and introduction of transgenic animals or birds with disease resistance, increased or higher nutritional value meat or milk production, or as biofactories for pharmaceuticals (Machuka 2004). The science and development technology is available, but the barriers are regulatory requirements, market forces, safety concerns and consumer acceptance, in short the same range of issues as described for crops (Powell, 2003; van Eenennaam, 2006; van Eenennaam and Olin, 2006).

Option: Further develop reproduction and breeding technologies and adopt them within the framework of comprehensive breeding programmes.
Assessment: Technologies like artificial insemination and embryo transfer have become routine in developed countries and they have been successfully transferred and introduced in other parts of the world (Wieser at al., 2000). However, the potential of these breeding technologies is exploited to a limited extent only due to insufficient adaptation to local conditions, problems with logistics and poor support with regard to breeding services and information management (Ahuja et al., 2000). There is scope to further develop these breeding technologies in particular through North-South cooperation. In order to effectively use these conventional breeding technologies, development of adequate breeding policies, programmes and plans is a must, though it continues to be a challenge for many countries (Chacko and Schneider, 2005). In this regard it is not a copy-paste of existing policies and programmes from one country to another but development of area specific solutions (Kurup, 2003).

6.1.2.3 Challenge: Responding to the increased demand for livestock products without additional threats for the environment.

Option: Cover the additional demand for animal protein with meat from monogastric animals (pigs and poultry) and eggs.
Assessment: The growth projections for ruminants are smaller than for monogastric animals. This development may be positive with regard to the direct pressure on (grazing) land, but will result in the establishment of large production units which are often placed in peri-urban areas. Animal feed is produced elsewhere, while disposal of waste from these large units has become in many cases an environmental issue (FAO, 2006). Although large pig and poultry farms may generate some employment opportunities, the capital required will probably exclude small farmers from playing a big role in this sub-sector. Ways and means have to be searched to increase the total efficiency of these production systems without additional threats to the environment. The approach of Area-Wide Integration (AWI) as developed and promoted by LEAD (Livestock Environment and Development Initiative, 2000) might become a suitable tool to address these issues. Recent outbreaks of diseases, some even threatening not only animal but also human health are an additional reason to carefully look at these large livestock units and their sustainability in wider terms, i.e. with regard to environment and health. The concentration process towards large pig and poultry farms for meat and eggs will continue (Steinfeld et al., 2006). It is therefore a must to deal with this form of livestock production and address potential problems caused by these units. AWI is the actual tool in dealing with these issues.

Option: Encourage small farmers in rural areas to concentrate on the production of meat and livestock products for the local markets and on the production of niche produces of high values.
Assessment: In this context and linked to the Millennium Development Goals, FAO launched in 2001 its Pro-Poor Livestock Policy Initiative (PPLPI, 2001). In most low-income countries local markets are supplied by local producers, and market channels are often “informal”, e.g. direct sale to local traders or on weekly local markets (Staal, 2000). Research and promotion for improved production methods based on farming systems which combine crop and livestock production are means which continue to be of interest for producers in rural areas (Abegaz, 2005).

For small-scale farmers in rural areas, the local markets will remain the main places where they sell their produces. In order to cater in an efficient and economically interesting manner for these markets, researching and promoting adequate production systems and value chains stay in the foreground (Moran, 2005; PPLPI, 2007). Wherever or as far as possible, the aim should be to integrate livestock production within prevailing cropping systems.

Processing of meat and livestock products into high value niche produces for far off markets might be interesting for economic reasons but immediately poses a number of risks (FAO, 1999). In this field, marketing becomes very crucial; a challenge which rarely can be taken up by the producers themselves. Farmers, even if they form themselves into cooperatives, would have to link with other market stakeholders, thereby risking that most of the "additional" product value is eaten away by their marketing efforts. Furthermore, with regard to meat and livestock products rural processors face difficulties to meet the quality standards to compete for far off urban or export markets (ILRI, 2006). On the other hand, there are processed products which find a market among the local population, although they would find it hard to end up on the shelves of urban supermarkets.

Examples of locally produced products
"Churpi" a stone-hard cheese from yak milk is produced and locally marketed in Sikkim; "sour milk" is produced and consumed in the Southern Highlands of Tanzania (as there is no way to pasteurize milk and transport it over 800 km to the market in Dar es Salaam)

Option: Extension of grazing land for increased numbers of ruminants kept under pastoral and rangeland systems.

Assessment: Further extension of grazing land to produce meat from ruminants is not a sustainable way to meet the growing demand for meat and livestock products (Steinfeld et al., 2006). Many of these systems are not too productive, while at the same time forest conversion to gain grazing land as well as insufficient pasture management resulting in overgrazing have become major concerns. Therefore, it is concluded that pastoralists will not really benefit from an increased demand for livestock products unless they are able to improve their present production systems by an efficient use of existing resources, i.e. breed improvement (Köhler-Rollefson, 2003) improvement of animal health and disease control

(Ramdas and Ghotge, 2005), of grazing regime and pasture management, and if possible supplementary feeding during times of limited grazing.

6.1.3 Pest and disease management

Agricultural pests (insect herbivores, pathogens, and weeds) will continue to reduce productivity, cause losses post harvest and threaten the economic viability of agricultural livelihoods.

6.1.3.1 Challenge: Enhance AKST's capacity to predict how and where new pest threats will arise.

New pest invasions, and the exacerbation of existing pest problems, are likely to increase with future climate change. For example, warmer winters will lead to an expansion of insect and pathogen overwintering ranges (Garrett et al., 2006), with limited evidence that this process is already under way for plant pathogens (Baker et al., 2004; Rosenzweig et al., 2001). Within existing overwinter ranges, elevation of pest damage following warm winters is expected to intensify with climate change (Gan, 2004; Gutierrez et al., 2006; Yamamura et al., 2006). Increased temperatures are also likely to facilitate range expansion of highly damaging weeds, which are currently limited by cool temperatures, such as species of Cyperus (Terry, 2001) and Striga (Vasey et al., 2005). Range expansion of wind-dispersed pests and pathogens could increase, with increases in the frequency and intensity of tropical storms and hurricanes (Zan et al., 2006). Global trade of agricultural goods will also accelerate species invasions.

Option: Improve techniques for investigating pest-host dynamics under environmental change. The future capacity to discern how pests, vectors, and hosts respond to abiotic and biotic stresses will be important for discriminating between climatic and nonclimatic influences, which in turn could provide better information for estimating pest damage potential under climate change. Options for accomplishing this include continued advances in genomics, such as those related to high-throughput analysis of gene expression (Garrett et al., 2006), and advances in mathematical approaches for modeling uncertainties and nonlinear thresholds, and their integration into General Circulation Models (Bourgeois et al., 2004; Garrett et al., 2006). Lastly, more observational studies are needed for evaluating the combined effects of increased temperatures and elevated CO_2 on pest-host dynamics (Hoover and Newman, 2004; Zvereva and Kozlov, 2006).

Assessment: Increased computational power is likely to facilitate advances in modeling techniques for understanding climate change impacts on pests. However, the predictive capacity of these models could continue, as it currently is, to be hampered by scale limitations of data generated by growth chamber and field plot experiments, and by inadequate information concerning pest geographical range (Chakaborty, 2005; Scherm, 2004). Greater focus on addressing these limitations is needed. Also, improved modeling capacity is needed for understanding how extreme climate events trigger pest and disease outbreaks (Fuhrer, 2003). Focusing modelling efforts on pests of tropical agriculture would likely have the greatest impact on helping AKST to address food security challenges, as these regions are projected to be most negatively impacted by climate change.

Option: Improve early detection of new pest invasions, and predict where new threats may appear. This could be accomplished through continued advances in remote sensing, including the linking of remote sensing, predictive models, and GIS (Carruthers, 2003; Strand, 2000), as well as coupling of wind dispersal and crop models to track wind-dispersed spores, seeds and insects (Kuparinen, 2006; Pan et al., 2006). Also, continued advances in the use of molecular tools, such as diagnostic arrays, will be needed to better identify the emergence of new pest problems, adequately differentiate pathovars, biovars, and races, and monitor their movement in the landscape (Garrett et al., 2006).

Assessment: The future use of molecular methods for pathogen identification has excellent potential in high-income countries. However, the spread of these technologies to low-income countries will likely to continue to be impeded by high equipment costs. The further development and dissemination of low-cost thermocyclers for PCR (polymerase chain reaction) techniques could help to address this need. In general, a lack of training and poor facilities throughout much of the developing regions hinders the ability to keep up with, let alone address, new pest threats. Recent advances in remote sensing have increased the utility of this technology for detecting crop damage from abiotic and biotic causal factors, thus remote sensing has good prospect for future integration with GIS and pest models. Lastly, options A and B should be integrated to the extent possible.

6.1.3.2 Challenge: Develop future pest management strategies that are responsive to threats posed by climate change and invasive species.

Several current AKST strategies for managing agricultural pests are likely to less effective in the face of climate change, thus reducing the flexibility for future pest management in the areas of host genetic resistance, inundative biological control, cultural practices, and pesticide use (Bailey, 2004; Garrett et al., 2006; Patterson, 1999; Stacey, 2003; Strand, 2000; Ziska and George, 2004). For example, loss of durable host resistance can be triggered by deactivation of resistance genes with high temperatures, and by host exposure to a greater number of infection cycles, such as would occur with longer growing seasons under climate change (Garrett et al., 2006; Strand, 2000). In addition to climate change, the recent emergence of highly virulent forms of plant disease, such as a new race of Puccinia graminis, causal agent of wheat stem rust, and recombinant hybridization of geminiviruses that cause cassava mosaic disease (Section 3.x.x), severely challenge AKST's ability to use plant breeding to stay ahead of disease threats.

Elevated CO_2 could also negatively impact future weed management. Recent evidence from CO_2-enrichment studies indicates that invasive weed species are significantly more responsive to elevated CO_2 than crops, and that weeds allocate more growth to root and rhizome than to shoot (Ziska et al., 2004). This shift in biomass allocation strategies by weeds could result in the need for more intensive tillage operations, and it could dilute the effectiveness of post-emergence herbicides (Ziska and George, 2004; Ziska and Goins, 2006). Elevated CO_2 is also predicted to favor the activity of Striga and other parasitic plant species (Phoenix and Press, 2005), which currently cause high yield losses in African cereal systems.

Option: Address the potential reduction in resistance durability. Options for enhancing the effectiveness of host genetic resistance include shifting the focus of breeding towards the development of multi- rather than single-gene resistance mechanisms (CIMMYT, 2005), pyramiding of resistance genes where multiple minor or major genes are stacked (Witcombe and Hash, 2000), production of transgenes that target pest binding and receptor sites of the host (Raman, 2003), and through expanding the use of varietal mixtures (Burdon et al., 2005; Smithson and Lenne, 1996).

Assessment: Multi-gene resistance, achieved through the deployment of several minor genes with additive effects rather than a single major gene, could become an important strategy where highly virulent races of common plant diseases emerge, as in the case of the Ug99 race of wheat stem rust for which major gene resistance has become ineffective (CIMMYT, 2005). Integration of genomic tools, such as quantitative trait loci (QTL) and marker-assisted selection (MAS) will be an important element of future resistance breeding.

Gene pyramiding has potential to become a future strategy for broadening the range of pests controlled by single transgenic lines. For example, expressing two different insect toxins simultaneously in a single plant may slow or halt the evolution of insects that are resistant, because resistance to two different toxins would have to evolve simultaneously (Bates et al., 2005; Gould, 1998), and the probability of that happening is extremely low. However, the long-term effectiveness of this technology is presently not clear. For example, the use of gene pyramiding also runs the risk of selecting for primary or secondary pest populations with resistance to multiple genes when pyramiding resistance genes to target a primary pest or pathogen (Manyangarirwa et al., 2006). Gene flow from stacked plants can accelerate any undesirable effects of gene flow from single trait transgenic plants. This could result in faster evolution of weeds or plants with negative effects on biodiversity or human health, depending on the traits.

Varietal mixtures, in which several varieties of the same species are grown together, is a well-established practice, particularly in smallholder risk-adverse production systems. While this practice generally does not maximize pest control, it does provide yield stability and can be more sustainable than many allopathic methods as it does not place high selection pressure on pests (Smithson and Lenn, 1996). Varietal mixtures could play an important role in enhancing the durability of resistance, such as with white-fly transmitted viruses on cassava (Thresh and Cooter, 2005). Research on varietal mixtures has been largely neglected by AKST. Thus, more research is needed to identify appropriate mixtures in terms of both pest resistance and agronomic characteristics, and to backcross sources of pest and disease resistance into local and introduced germplasm (Smithson and Lenne, 1996).

Future breeding efforts will need to include greater farmer involvement for successful uptake and dissemination (Gyawali et al., 2007; Joshi et al., 2007). Farmer-assisted breeding programs, where farmers work with research and extension to develop locally acceptable new varieties, has a much greater success rate than a top-down approach of disseminating new varieties developed on research stations. Also, better development of seed networks will be needed to improve local access to quality seed.

6.1.3.3 Challenge: improve plant root health.

The ability of AKST to effectively address yield stagnation and declining factor productivity in long-term cropping systems will depend on efforts to better manage root disease. For example, plant-parasitic nematodes, a key biotic constraint to good root system establishment and function, is often misdiagnosed because symptoms of nematode damage closely resemble that of poor plant nutrition and drought stress (Luc et al., 2005). The fact that nematodes cause wilting of the host plant under mild heat stress or water deficit conditions makes them an important biotic stress factor for crop response to seasonal dry spells and heatwaves. With future temperature increase, crops that are grown near the upper thermal limit for their production in areas with high nematode pressure, such as wheat in the Eastern Indo-Gangetic Plain, could become increasingly susceptible to yield loss from nematodes. Additionally, the large-scale transition in Asia from flooded to aerobic rice is likely to create greater opportunities for future nematode damage on that crop (Bridge et al., 2005).

The management of soilborne pests (plant-parasitic nematodes, fungal and bacterial pathogens) is at a crossroads, with the pending loss of important chemicals (methyl bromide and nonfumigant nematicides), and the emergence of new molecular tools and biologically based control systems (Sikora et al, 2005). Future AKST will be confronted with a number of possible directions for managing soilborne pests which will depend on the type of system (organic or conventional), the need for uniformity to market standards, and access to useable information derived from advances in knowledge of soil microbial community function.

Option: Continue fumigant substitution for methyl bromide (MB). The extension of critical use exemptions has left the phase-out of methyl bromide, a class 1 stratsopheric ozone depleting substance, in a partially suspended state. Given the increasing cost of MB and its future uncertainty, several currently registered preplant soil fumigants are being investigated for substitution of MB, including chloropicrin- and isothiocynate-based substances as well as other organic halogenated substances (Martin, 2003). These replacement fumigants are less effective than MB, though improved fumigant application methods including drip application under plastic mulching, and use of improved plastic film material for tarping could increase soil retention of the chemical and hence its effectiveness.

Assessment: Intensive high-value vegetable and annual fruit systems are likely to continue to rely on chemical fumigant methods for root disease control in the near-term. However, the alternative fumigants do not have the same broad-spectrum efficacy as MB, and their use appears to cause increased germination of nutsedge and others weeds, thus requiring combinations of fumigants and other pesticides at high concentrations to achieve results similar to MB (Martin, 2003). This situation will leave growers vulnerable to greater pesticide dependency as well as to future regulatory restrictions (Kokalis-Burelle and Kloepper, 2004).

Option: Increase use of pre-plant soil solarization. Soil solarization, the practice of heating the surface 5-10 cm of soil by applying a tightly sealed plastic cover, is a highly effective means of improving root health through killing or immobilizing soilborne pests, enhancing subsequent crop root colonization by plant-growth promoting bacteria, and increasing plant-available nitrogen (Chen et al., 1991).

Assessment: Soil solarization is an environmentally sustainable alternative to soil fumigation, though its application is limited to high value crops in hot sunny environments (Stapleton, et al., 2000), and its use for controlling nematodes is greatly enhanced when combined with other practices such as biofumigation, organic amendments, or cover crops (Orzores-Hampton et al., 2004). Soil solarization of nursery seedbeds is an important but underutilized application of this technology, particularly for transplanted crops in the developing world, where farmers contend with high densities of soilborne pests and have few if any control measures. For example, solarization of rice seedbed soil, which is commonly infested with plant-parasitic nematodes, can improve rice productivity in underperforming rice-wheat rotation areas of South Asia (Banu et al., 2005; Duxbury and Lauren, 2006). This technique could have good potential for broader application in transplanted crops with small seedling nurseries.

Option: Apply emerging molecular tools to rationalize the use of cultural practices that enhance soil suppressiveness of root disease. Several well-established cultural practices improve soil health, leading in some cases to increased disease suppressiveness. These include crop rotation, conservation tillage, use of green manures, composts and other organic

amendments, and manipulation of soil pH and fertility (Alabouvette et al., 2004; Janvier et al., 2007; Kokalis-Burelle and Kloepper, 2004). However, these practices tend to deliver inconsistent results across pathosystems, and they can cause emergence of secondary disease problems. Moreover, it has been difficult to discern clear relationships between use of these practices and disease suppression. Advances in genomics and molecular biology could aid in understanding the underlying mechanisms of soil disease suppression. For example, future advances in the application of polymerase chain reaction (PCR)-based molecular methods of soil DNA will enable greater understanding of functional diversity, and relationships between soil microbial communities and root disease suppression linked to soil properties and changes in crop management practices (Alabouvette et al., 2004).
Assessment: Many of the above-mentioned cultural practices contribute to the overall sustainability of agriculture, and will thus likely be important to future AKST. Advances in genomics and molecular biology have high potential to aid in improving the configuration of production systems for disease suppression. More broadly, advances in molecular methods for soil microbial characterization could improve understanding of global change processes in soil, such as how elevated CO_2 will impact feedbacks between root systems and soil related to rhizosphere activity and mycorrhizal establishment, and nutrient cycling of C enriched crop residues (Fitter et al., 2000; van Noordwijk et al., 1998). Efforts should be undertaken to develop expertise and capacity in the developing world for these tools, as discussed above.

Option: Enhance biological control potential of soilborne pests. Future nematode biocontrol could be made significantly more effective through shifting the focus from controlling the parasite in soil to one of targeting parasite life-stages in the host. This could be accomplished through the use of biological enhancement of seeds and transplants with arbuscular mycorrhiza, endophytic bacteria and fungi, and plant-health promoting rhizobacteria, combined with improved delivery systems using liquid and solid-state fermentation (Sikora and Fernandez, 2005; Sikora et al., 2005). Enhancing biocontrol potential could also be achieved through linking biological control research with molecular biology to understand how colonization by beneficial mutualists affects gene signaling pathways related to induced systemic resistance in the host (Pieterse et al., 2001). Insights gained from this research could provide novel ways of achieving the biological control effect by eliciting gene response as an alternative to using live microorganisms, thus obviating many of the problems associated with their production, storage and application.

Assessment: Biocontrol of soil pests will likely continue achieving significant strides at the experimental level, and yet still not have much of a future impact on field-based commercial applications of biocontrol. Addressing impediments related to scaling up biocontrol from controlled settings to field soil environments, the exceedingly high costs of registration, and lack of private sector investment will be needed to make root disease biocontrol a viable management tool (Fravel, 2005). The recent success in scaling up nematode biocontrol using a nonpathogenic strain of Fusarium oxysporum to control the highly destructive Radopholus similis, causal agent of banana toppling disease (Sikora and Pokasangree, 2004), illustrate how the alignment of several key factors— a very effective biocontrol agent, a highly visible disease problem with significant economic impact, and substantial private-sector investment— was necessary to allow for development of a potential commercial product.

6.1.4 Forestry and agroforestry systems

The ecological and socio-economic importance of traditional agroforestry systems is widely recognized. These land-use systems provide various useful products for household and national economies including food and medicinal products for humans and animals, wood for construction and fuel and cash income.

Option: Promote agroforestry systems as potentially effective in mitigating the abiotic impacts on forest remnants and promoting environmental services (AFS). are 50% indigenous trees and 50% introduced species (e.g., Schreckenberg et al., 2002; 2006). Mechanization and use of agrichemicals is commonly low, but cash-crop germplasm is often ‘improved’. The challenge for the future will be scaling this number up World Agroforestry Centre, 2005; Garrity, 2006).

Assessment: Agroforestry systems have high potential to achieve gender equity in property rights and may play a vital role in the coming years in helping reduce hunger and promote food security.. This is especially true in customary African land tenure systems where planting or clearing trees is a means of establishing claims, on the trees, but also on the underlying land (Gari, 2002; Gladwin et al., 2002; Villarreal et al., 2006).

The science and practice of agroforestry are complex it will be crucial to strengthen strategic partnerships and alliances in order to foster the role of agroforestry in tackling new challenges. One such example would be to use Agroforestry systems to improve soil fertility. Given the high cost of inorganic fertilizers, an integrated soil fertility management approach that combines promising agroforestry technologies – especially improved fallows of leguminous species and biomass transfer – with locally available and reactive phosphate rock (e.g. Minjingu of northern Tanzania) can increase crop yields several-fold.

Improved fallows can also contribute to the control of weeds and provide wood for energy and for staking climbing crops. For biomass transfer, use of Tithonia diversifolia is the most promising because of its high nutrient content and rapid rates of decomposition, but problems of scaling up remain and the method by which high-value trees, crops and livestock can be intensively farmed to provide a natural progression out of poverty (Jama et al., 2006).

Biotechnology applied to forestry genomics has reduced the slow and arduous process of forest tree improvement. Its approaches such as in-vitro propagation, gene transfer and marker-assisted breeding have brought genetic improvement of forest trees to a level of sophistication comparable with that routinely used for agronomic species (Merkle and Dean, 2000). Trees, however, are special with regard to determining environmental impact because of their long generation times. Thus it will be some time before economic improvements and safety assessments can be verified (Hoenicka and Fladung, 2006).

6.1.5 Fishery and aquaculture systems

6.1.5.1 Challenge: Better governance and management of wild fisheries is needed to halt the decline of fish stocks and protect future food security.

Globally, fisheries products are the most widely traded foods and the fastest growing “agricultural” commodity on international markets. In 2002, net exports amounted to US$17.4 billion in foreign exchange earnings for developing countries, a value greater than the combined net exports of rice, coffee, sugar, and tea. By 2015, over 80% of fish traded internationally is expected to come from developing countries, placing increasing importance on the future sustainable management of these valuable resources. (FOA statistics, 2002)

In spite of the important role that fisheries play in the national and local economies of many countries, the fisheries sector—as compared against other sectors of the world food economy—is poorly planned, managed and regulated, inadequately funded and neglected by all levels of government. Fisheries around the globe are frequently overfished and overexploited as a result of not only weak governance, but of poor management, perverse subsidies, corruption, unrestricted access and destructive fishing practices (World Bank 2004). Reforming both the governance and the management of these critical natural resources is essential to stable and long-term economic development, future food security, sustainable livelihoods, poverty prevention and reduction, continuation of the ecosystem goods and services provided by these natural resources, and the conservation of biodiversity. (Fisheries Opportunity Assessment 2007; Christie et al., 2007; Sanchirico and Wilen 2007).

Option: Strengthen fisheries governance through marine tenure and access privileges. Large-scale social and ecological experiments are needed to implement culturally appropriate approaches to marine tenure and access privileges that can be applied to both large-scale industrialized fisheries and small-scale artisanal fisheries (Fisheries Opportunity Assessment 2007; Pomeroy and Rivera-Guieb 2006). "Rights-based" or privilege-based approaches to resource access can alter behavioral incentives and align economic incentives with conservation objectives (Sanchirico and Wilen 2007).

Option: Strengthen fisheries governance and management through the use of large-scale seascape "zoning" for specific uses and user groups.

As in terrestrial systems, large-scale seascape planning and zoning is necessary to protect essential and critical fisheries habitats that are necessary for "growing" fisheries populations and maintaining ecosystem health. The science of large-scale planning is relatively young and further research and implementation is needed to refine the approach. Future zoning should allow for the most sustainable use of various marine habitat types for capture fisheries, low-trophic level aquaculture, recreation, biodiversity conservation and maintenance of ecosystem health. Ultimately, integrating landscape and seascape use designs are needed to conserve and protect ecosystem goods and services, conserve soils, reduce sedimentation and pollution run-off, protect the most productive terrestrial, wetlands and marine habitats, and promote improved water resources management – for the benefits of agriculture, people and nature.

Option: Develop socio-economic and environmental scenarios that explore the potential trade-offs and benefits from applying different management regimes to improve wild fisheries *management.* Scenarios could be used to improve political science, political will and the application of science to management decisions for reforming fisheries governance, both large-scale and small-scale fisheries, and incorporating cultural and indigenous knowledge (Fisheries Opportunity Assessment 2007; Philippart et al. 2007). For example, the Locally Managed Marine Areas (LMMAs) approach in the Pacific builds upon cultural practices of setting aside specific areas as off-limits to fishing for rebuilding fisheries and biodiversity. *Assessment:* In most cultures, wild fisheries and marine resources are considered as common property and suffer from open, unregulated access to these valuable resources. The concept of land tenure and property rights has been instrumental in reforming terrestrial agriculture and empowering small-scale farmers. Similarly, the concepts of marine tenure and access privileges are needed to address the "wild frontier" attitude generated by open access to fisheries and to promote shared responsibilities and co-management of resources (Pomeroy and Rivera-Guieb 2006; Sanchirico and Wilen 2007). Several traditional management approaches, such as in the Pacific Islands, have evolved that are based upon the concept of marine tenure.

For fisheries, major goals of zoning are to (1) protect the most productive terrestrial, wetland and marine habitats which serve as fisheries nurseries and spawning aggregation sites, and (2) allocate resource use -- and thus stewardship responsibility -- to specific users or user groups. Appropriate zoning would allow for the most sustainable use of various habitats types for capture fisheries, aquaculture, recreation, biodiversity conservation and maintenance of ecosystem health. Future zoning for specific uses and user groups would also shift shared responsibility onto those designated users, thus increasing self-enforcement and compliance (Sanchirico and Wilen 2007). Large-scale and local zoning would be particularly beneficial in those countries where government, rule of law and scientific management capacity is weak.

- Improving fisheries management is critical for addressing food security and livelihoods in many developing countries, where fishing often serves as the last "social safety net" for poor communities and for those who have no land tenure rights. Fisheries has strong links to poverty - at least 20% of those employed in fisheries earn less than US $1 per day – and children often work in the capture and/or processing sectors, exposing them to long work hours and/or dangerous working conditions. For 2.6 billion people in developing countries, fish provide more than 20% of animal protein consumed, compared to 8% in industrialized countries. In some developing countries, fish actually provides up to 50% of the animal protein consumed.

- Fisheries also provide an important source of livelihood and income for 1.5 billion men, women and children, with the majority (87%) of the world's fishers and aquaculture workers in developing countries. Women often play a significant role in fish trading for local and sub-national markets, as well as small-scale cross-border trade, while men more often dominate national and international-level fish trade. Worldwide, 96% of fishers are small-scale, and these fishers produce approximately 58% of global fish catches annually. The number of part-time fishers increased more rapidly than full-time fishers between 1970 and 1990: the number of full-time fishers doubled while the number of part-time fishers increased 160%. The number of full-time fishers has been growing at an average rate of 2.5% per year since 1990—a total of 400% since 1950 (by comparison, the number of agricultural workers increased by 35% in the same period), and is projected to continue to increase. (Fisheries Opportunity Assessment 2007; Sugiyama et al. 2005).

6.1.5.2 Challenge: Develop management approaches that will restore ecosystem productivity and resilience.

Marine, coastal and freshwater ecosystems have been drastically altered over the past 50 years, reducing their productivity, resilience to stress, and potential to contribute to future food security. The total world production from wild fisheries has declined in recent years due to the lack of poor management, inappropriate fishing practices and poor understanding of ecosystem-based management approaches. Future projections indicate that wild fisheries will continue to decline, aquatic ecosystems and their free goods and services will collapse, and food security will be seriously threatened unless new management approaches are developed and implemented (Olsen et al., 2006; Pauly et al., 2005; Schrank, 2007; Worm et al., 2007.) In many ways, fishing technology has outpaced the development and application of sound science and management. The development and unregulated use of large-scale trawling, gill nets, long-lining, and small-scale use of other destructive fishing practices, such as dynamite and cyanide, has damaged the productivity of ecosystems and habitats upon which fishing depends (Grey et al. 2006).

Option: Develop and utilize ecosystem-based fisheries management approaches .An ecosystem-based approach to fisheries management (EBFM) focuses on conserving the underlying ecosystem health and functions, thus maintaining ecosystem goods and services (Pikitch et al. 2004). Developing EBFM requires an understanding of large-scale ecological processes; identifying critical fisheries nurseries, habitats and linkages between habitats, such as between mangrove forests and coral reefs; understanding freshwater inflows into coastal estuaries and maintaining the quantity, quality and timing of freshwater flows that make wetlands some of the most productive ecosystems in the world; and how human activities, such as fishing, impacts ecosystem function (Bakun and Weeks 2006; Hiddinks et al. 2006; Lotze et al. 2006; Olsen et al. 2006). EBFM also requires protection of essential fish habitats and large-scale regional use planning.

Option: Design and establish large-scale networks of fisheries reserves. The design and establishment of networks of fisheries reserves are necessary to improve and protect fisheries productivity, as well as improve resilience in the face of climate change and increasing variability. Well-designed and placed fisheries reserves, which restrict all extractive uses, are needed to rebuild severely depleted ecosystems and fisheries and to serve as “insurance” against future risks; however, critical science gaps will need to be addressed before fishery reserves can be effectively utilized (Gell and Roberts, 2003; Sale et al., 2004).

Option: Develop non-linear, multi-species approaches to fisheries management. The concept of “maximum sustainable yield” and managing by a species-by-species or population-by-population approach has not proved effective methodologies for fisheries management given the complexity of ecosystems and food-webs. Overfishing and “fishing down the food web” has occurred, seriously threatening the future productivity of wild fisheries (Pauly and Adler 2005). New fisheries models and approaches need to be developed and applied for determining more sustainable levels, types and sizes of fish extracted.

Option: Design and develop more environmentally-friendly extraction technology to restore and protect fisheries productivity and biodiversity. Fishing is the largest extractive use of wildlife and biodiversity in the world. Extraction technologies, however, threaten the future health and productivity of fisheries and aquatic ecosystems. Non-selective gear removes non-target fish, resulting in significant “bycatch” that is returned dead to the sea, and can detrimentally alter the population structure and increase variability in population structures

(Pauly and Adler 2005; Hsieh et al. 2006). Bottom-trawling can also destroy the essential fish habitat needed for future fish populations (Dew and McConnaughey 2005).

Option: Promote more environmentally-friendly and sustainable aquaculture that does not compromise the health and productivity of wild fisheries and marginalize smallholders. While aquaculture is one of the fastest growing food sectors in productivity, this achievement has been at great cost and risk to the health and well-being of the environment, as well as the well-being of small fishers and farmers. The future of aquaculture is truly at a crossroads: the future direction of aquaculture will impact the health and productivity of wild fisheries, the survival of many smallholders' livelihoods, and global food security (World Bank 2006).

About 30% of capture fisheries are currently used to create "fish meal" destined for aquaculture and other livestock, and this percentage is expected to increase as aquaculture expands and more high-trophic level fish (such as salmon, grouper and tuna) are cultured and . Ill-placed and designed aquaculture facilities have also reduced the productivity of wild fisheries and degraded environments through loss of critical habitats, especially mangrove forests and coral reefs; introduction of invasive species, pests and diseases; and use of pesticides and antibiotics.

Assessment: EBFM approaches are relatively new management tools that are only beginning to be developed. Given the ecological complexity of ecological systems, especially the tropical systems in many developing countries, the application of EBFM needs to be further developed and assessed. Major governance and ecological challenges exist as management is scaled up in geographic area. Institutional, governance and environmental challenges will require monitoring, evaluation and adaptive management. (Christie et al. 2007)

Greater emphasis is needed to develop sound fisheries "growth" practices and approaches – such as EBFM, networks of reserves, new quota models and new extraction technology -- which will restore ecosystem productivity and resiliency. It is estimated that with proper fishing practices, capture fisheries production could increase five-fold.

Aquaculture is one of the most rapidly increasing agricultural sectors, yet its future contribution to global food security and livelihoods will depend on the promotion of more environmentally sustainable and less polluting culture techniques; the use of low-trophic level species, especially filter-feeding species; appropriate siting and management approaches;

and inclusion and empowerment of smallholders (World Bank, 2006). A more balanced approach to aquaculture is needed that incorporates environmental sustainability, integrated water resources management and equitable resources use and access to benefits.

6.1.5.3 Challenge: Global climate change will alter marine and freshwater ecosystems and habitats, fish distributions and hydrological cycles.

While the broad implications of climate change on marine systems are known – including rising sea levels, sea surface temperatures, and acidification – the degree and rate of change is not known, nor the impacts of these physical changes on ecosystem function and productivity (Behrenfeld et al. 2006). To adjust and cope with future climatic changes, we need to increase our understanding of how to predict the extent of change, apply adaptive management, and assign risk for management decisions (Schneider 2006).

Option: Advance understanding of potential and realized impacts from climate change and develop appropriate strategies for mitigating impacts. To ensure the survival of many communities, their livelihoods and global food security, we need to develop new approaches to monitoring, predicting, and adaptively responding to changes in marine and terrestrial ecosystems. Future AKST needs to focus on building ecosystem resilience into fisheries and essential fish habitats (including wetlands and estuaries) and developing approaches that reduce risk and ensure continuation of ecosystem goods and services (Philippart et al. 2007). Rising sea levels will alter coastal habitats and their future productivity, threatening some of the most productive fishing areas in the world. Changes in ocean temperatures will alter ocean currents and the distribution and ranges of marine animals, including fish populations (Clark et al. 2007; di Prisco and Verde 2006; Lunde et al. 2006; Sabates et al. 2006). Rising sea surface temperatures will result in additional coral reef bleaching and mortality (Donner et al. 2005). Rising atmospheric CO2 will is lead to acidification of ocean waters and disrupt the ability of animals (such as corals, mollusks, plankton) to secrete calcareous skeletons, thus reducing their role in critical ecosystems and food webs (Royal Society 2005).

Assessment: Small-scale fishers, who lack mobility and livelihood alternatives and are often the most dependent on specific fisheries, will suffer disproportionately from such large-scale climatic changes. In Asia, 1 billion people are estimated to be dependent upon coral reef fisheries as a major source of protein, yet coral reef ecosystems are among the most threatened by global climate change. The combined effects of sea surface temperature rise and oceanic acidification could mean that corals will begin to disappear from tropical reefs in just 50 years; poor, rural coastal communities in developing countries are at the greatest risk and will likely suffer the greatest consequences of this impact (Donner and Potere 2007). Climate change is a major threat to critical coastal ecosystems such as the Nile, the Niger and other low-lying deltas, as well as oceanic islands which may be inundated by rising sea levels. The environmental and socioeconomic costs, especially to fisheries communities in developing countries, could be enormous.

6.2 Farming system improvement

6.2.1 Challenge: improve the efficiency and productivity in an environmentally and socially sustainable way

Considerable potential exists to improve livelihoods and reduce environmental impact by applying existing AKST in smarter ways to optimize farming (cropping and livestock) systems, especially in developing countries.

6.2.1.1 Option: Building on agricultural knowledge and innovation in local and indigenous societies

Option: Engaging local and indigenous knowledge systems and grassroots innovation capacities, giving them more determined recognition, legitimacy and upgrading. Empower communities to access to knowledge and to participate in innovation processes so that they get wider and stronger options to respond to new changes and challenges (Crains 2006, Colfer 2005). Develop a new agenda that builds on agricultural knowledge and innovation in local and indigenous societies: increase participatory agricultural and environmental research projects that bring together indigenous and western science (Colfer 2004, Brookfield et al. 2003), specific journals such as Etnoecologica, and academic courses that are targeting indigenous knowledge as indispensable for agricultural innovation and development. Farmer Field Schools could play a vital part as a community-based initiative for participatory research, enabling farmers to regularly meet to define themselves their farming problems, analyse them and experiment solutions using their own capacities and knowledge. Seed fairs, which foster the exchange of knowledge on crops and crop varieties, could becoming widespread events in rural areas. The establishment of “Lead farmers” and the implementation of various grassroots extension mechanisms could have a key role in reinforcing the role of communities in the production and diffusion of knowledge.

Assessment: Agricultural knowledge and innovation often are domains for specialists, such as researchers, engineers and extension agents. Rural people are perceived as recipients and applicants for such knowledge and innovation. This alienation has eroded local knowledge systems and the grassroots abilities for innovation (Nathan et al. 2004).
Most agricultural knowledge and technology focus on farming systems that have surpluses of land, labor and capital. However, millions of small-scale farmers in the world, who are precisely among the poorest people, have little of these productive resources. Consequently, much knowledge and technology produced through formal institutions results inappropriate for these rural majorities.

Many innovations for improving AKST occurred at the community level, and were diffused through community institutions (Gyasi et al., 2003). For example, communities across the world have domesticated dozens of plant species, have bred and conserved thousands of crop varieties, and have developed farming systems and practices adapted to specific conditions (Kaihura. and Stocking, 2003). Tapping on those resources and capacities, giving them more determined recognition, legitimacy and upgrading will therefore be a key goal for development stakeholders. Science, which builds substantially on indigenous farming knowledge, practices and experimentation, like agroecology, is becoming a priority in rural areas (Altieri, 1995). This new paradigm has the potential to enrich the production and deployment of new farming practices and technologies, ensuring that they are more sustainable in environmental, social and cultural terms (Koontz T. M. et al. 2004).

6.2.1.2 Ecoagriculture

Option: Wider adoption of ecoagriculture without compromising food security or environmental and social sustainability. Ecoagriculture, low external input systems that rely on natural and renewable processes, has the potential to improve environmental and social sustainability whilst maintaining or increasing levels of food production. There is now increasing evidence of the productive potential of ecological agriculture (IFOAM, 2007; Pretty, Bagley et al., in press).
Assessment: There is now enough evidence to show that the transition to a more ecological based agriculture is not a threat to food security. Pretty et al., 2003 in a survey of more than 200 projects from Latin America, Africa, and Asia, all of which addressed the issue of sustainable land use, found a general increase in food production and agricultural

sustainability. Likewise, low external input crop systems, when properly managed, have demonstrated the potential to increase agricultural yield with less impact to the environment (Bunch, 1999; Tiffen and Bunch, 2002). While in high external input agriculture yield reductions up to 20% are frequent during and after transition to organic farming (Mäder et al., 2002; Poudel et al., 2002; Pimentel et al., 2005), organic and sustainable agricultural practices in low external input systems are reported to increase yields up to five times (El-Hage Scialabba and Hattam, 2002; Rasul and Thapa, 2004; Blaise, 2006; Pretty et al., 2006).

A recent investigation comparing organic with conventional farming experiences from different parts of the world indicates that sustainable agriculture can produce enough food for the present global population and, eventually an even larger population, without increasing the area spared for agriculture (Pretty et al., 2003; Pretty et al., 2006; Badgley et al., In press). Adoption of agroecological methods by smallholders and poor farmers in developing countries has the potential to increase food production through different mechanisms (Holt-Giménez, 2001).

Option: Potential to improve environmental services. Some contemporaneous studies also show the potential of ecological agriculture to promote environmental services, for example agroforestry systems (Montagnini and Nair, 2004).
Assessment: In the zero-tillage, or no-tillage system, mainly grain crops such as soybean and corn, are cultivated without plowing the soil (Landers, 1999; Landers, 2001) and show a substantial advantage. Souza and Melo (2003) have also demonstrated an increase in soil organic matter in corn systems cultivated under no-till systems. In addition to promoting soil improvement and increasing yield, the no-till method has also been shown to prevent erosion, save energy (particularly fossil fuel), enhance biodiversity, and reduce weeds and diseases (Landers, 2001; Callegari, 2002; Seguy, Bouzinac et al. 2003). The concept of energy efficiency is directly related with another important concern in designing sustainable agricultural systems, in which optimization is the highest possible yield of any given system without compromising its integrity (Gliessman, 1998).

Opinion is divided on whether food production, environmental protection, and livelihood enhancement can be simultaneously promoted (Lee, Ferraro et al., 2001; Borlaug, 2000; Waggoner, 1997; Green et al., 2005; Matson and Vitousek, 2006; Pretty, Badgley et al., In press) In spite of the advantages of sustainable agriculture in combining poverty reduction, environmental enhancement and food production, few studies address the issues of how to assess the tradeoffs (Scoones, 1998). In the same way, the concept of ecological agriculture needs a better understanding of the relationship among the multiple dimensions of rural development, i.e., agricultural productivity, environmental services, and livelihood. Such questions are still open for further elaboration and pose a challenge to AKST (Buck, Gavin et al., 2004; Jackson, Pascual et al., In press).

Option: Enhance the utilization of functional linkages between agricultural biodiversity and resilience to pest and disease outbreaks. There is a wide range of well-established practices for utilizing agro-biodiversity to manage pests. Future AKST can enhance the use of biodiversity for pest control through expanding, where appropriate and feasible, practices such as intercropping, mixed cropping, varietal mixtures, retention of beneficial noncrop plants, crop rotation, and improved fallow (Altieri, 2002). The underlying principal of using biodiversity for pest control is to reduce the concentration of the primary host and to create conditions that increase natural enemy populations (Altieri, 2002).

Assessment: This approach has multiple benefits in addition to pest management, including C sequestration, maintenance of biodiversity and clean water, and enhanced resilience to climate variability. Recent advances in understanding weed community genetics could aid in the process of developing diverse agroecosystems that have greater resilience to invasive species (Clements et al., 2004). The process of designing systems to achieve multiple functions is very knowledge intensive and often location specific. The challenges for AKST will be to maintain currently diverse systems and the knowledge therein, and to better elucidate the underlying pest suppression mechanisms and overall benefits of agro-biodiversity to sustainable agriculture. As a starting point, AKST could take stock of where diverse systems exist, the institutional dynamics that influence them, where opportunities exist to scale them up, and better quantify how diversification impacts adaptive capacity to climate change.

6.2.1.3 High input, intensive systems

[We have no text for this yet – asking NAE assessment team for help]

6.2.1.3.1 Precision agriculture, remote sensing, agrometeorology.

Option: *Harnessing new advances in satellite-based and space technologies for the benefit of agriculture.* Remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS) supported by advanced tools like computer, digital camera, image processing technique, laser technology, and network system have the potential to be powerful tools in precision and site-specific agriculture (PA) resulting in improvements in agricultural performance and sustainability.

Option: Developments in remote sensing technology will permit extension of the range of current applications. These include mineral and oil exploration, crop monitoring, natural resource management urban and transportation planning, social science (De Sherbinin et al. 2002), applied geosciences (Mukherjee, 1999), forestry, agriculture, wildlife conservation, environmental change, pedology, oceanography, geology, meteorology, human and health epidemiology (Hay, 2000), biodiversity assessment (Zutta 2003; Rao 2005), agricultural meteorology (Sivakumar and Hinsman, 2003).
Remotely sensed data is also important in agricultural planning which complements traditional methods of agrometeorological data collection (Sivakumar and Hinsman, 2003) disaster management and crop condition assessments (Rao, 2005).
Assessment: In agriculture, adoption of RS techniques will improve performance in crop identification, crop area inventory, yield forecasting, soil and water resources inventory, and assessment of flood damage (Van Niel and McVicar, 2001; Patil et al., 2002; Syam and Jusoff, 1999) and contribute to the information needs of precision agriculture (PA) in the assessment of soil and crop conditions using multi-spectral imagery (Barnes et al., 1996). Higher crop classification accuracies can be achieved by combining GIS and RS data (Aplin et al., 1998; Sakthivadivel et al., 1999); and using multi-temporal data (Kurosu et al., 1997; Panigrahy et al., 1997), and use of multi-sensor data (Le Hegarat-Mascle et al., 2000; Okamoto and Kawashima, 1999).

Yield forecasts can greatly influence farm-level management decisions: fertilizer applications and water delivery; provide a means for farm income assessment (Van Neil and McVicar, 2001); and serve as reference to policy level decisions related to food security, poverty alleviation, and sustainable development (Patil et al., 2002), among others.

Option: Soil and water resources inventory. Using time series, RS could identify and demarcate underutilized lands. For instance, RS is able to gather important data such as qualitative description of the causal factors for underutilized lands and more effective technology transfer (Chandna et al., 2004). RS could assist in more complex water management tasks: irrigation system performance evaluation, snowmelt runoff forecasts, reservoir sedimentation and storage loss assessments, prioritization of watersheds and their treatment, environmental impact assessment of developmental projects, prospecting of underground water, location-specific water harvesting and recharge, and interlinking of rivers and monitoring of spatial and temporal distribution of rainfall, etc. (Thiruvengadachari et al., 1996).

<u>Assessment:</u> Given more time and resources applications of RS on crop, soil, and water inventory and monitoring, agro-environment health and forecasting could enhance agricultural performance. Nationwide wasteland, land use, land cover and soil mapping will also help expand and intensify agricultural activities and identify land capability classes and crop suitability indices (Patil et al., 2002). This will not only enhance total agricultural productivity, but also partial factor productivity of inputs of specific crops (Johannsen et al., 2005); help maximize the efficiency of crop inputs within small areas of the farm field (Covey, 1999); automated data collection and mapping (Swinton and Lowenberg-Deboer, 2001); establish proper management strategies (Clarke, 1996); help save energy and time, and preserve soil ecology (Johannsen et al., 1996; Adamchuk, 2001); optimize fertilizer- and pesticide-use efficiency (Lowenberg-DeBoer 2003; Hong et al. 2006) thereby, decreasing their detrimental effects to the environment.

To optimize water use, hyperspectral remote sensing holds the greatest promise for estimating moisture within the crop (Miller 2002) and offers quick regional measurements that cannot be achieved by current ground-based sampling techniques (Gonzales-Dugo 2006). For example, the use of Jupiter GPS and the positioning method can help monitor and control the speed and direction of irrigation machinery (Xiachao et al., 2004). Reviews above show the richness and potential uses of RS in agriculture, particularly in PA. RS is a valuable tool to fulfill the goals of PA toward optimizing crop production and minimizing environmental pollution and degradation, leading to a more sustainable development in general (Griepentrog and Blackmore, 2004). Thus, RS specifically its uses in precision farming is a promising management system in line with IAASTD goals.

6.2.1.3.2 Information communication technology (ICT)

Option: Use of ICT to transform the efficiency of agricultural practice (Association of African Universities, 2000).

Assessment: instead of bridging the knowledge gap, ICTs are believed to further widen the "digital divide" between developed and developing countries, as well as between rural and urban communities within a country (Herselman, 2002), that can diffuse ideas around the globe in a matter of seconds, which in the past had taken years or centuries (Kluver, 2000).

ICTs' applications in agriculture includes the possibility of operating a farm over the internet with farmers able to open gates, track livestock, steer tractors, and run the whole farm via the Internet, from anywhere on earth (Pocknee, 2004). Defining and bridging the 'digital divide', although ICT allows greater and faster flow of information, not all people have access to the channels by which information is being transmitted. ICT only caters to those who have the access to and knowledge of the technology. With this, instead of connecting and converging people together, ICT has created disparity or divergence.

6.2.1.3.3 Nanotechnology.

Nanotechnology holds much promise in revolutionizing science and technology and is the control of matter at the nanometer scale (1–100 nanometers, one nanometer being equal to 1 × 10^{-9} of a meter), and the exploitation of novel phenomena and properties of matter at that scale (Salamanca-Buentello et al., 2005).

Option: Increase development of agricultural applications of nanotechnology. The commercial applications of nanotechnology are expected to grow and have a significant impact in areas of relevance to agriculture (Binnig and Rohrer 1985; Mills et al. 1997; Graham-Rowe 2006; Huang et al. 2001; Hossain et al. 2005; Dutta et al. 2004; Vayssieres et al., 2001; and Bayer, Inc., 2003). The effect of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in the last century (US NSTC 2000).

Better integration of nanotechnology, biotechnology, and information and communications technology could also contribute to ISAADT goals (Opara 2004). For example, biosensors developed into nanosensors will expedite automatic rapid testing and analysis for soil, plant, and water (Alocilja and Radke, 2002; Birrel et al., 2001).

Assessment: Nanotechnology is one of the platform technologies because it is inherent in the materials behind all fundamental industries. As such, it can and will directly influence human health and the environment as well as offer the potential to dramatically reduce human impact on the planet. Likewise, as a platform technology, any adverse consequences will also be quickly spread on a global scale.

Option: Development of nanomaterials for remediation of agricultural soils. Nanomaterials might be used as environmental filters or as direct sensors of pollutants (Dionysiou, 2004).

Assessment: Returning nutrients to, and removing contaminants from, agricultural areas, will continue to be a significant challenge for sustainable agriculture in an ever smaller available space for agriculture. Nanotechnologies are too young to have developed a track record from which to extrapolate their long-term usefulness and safety (Colvin, 2003; Dionysiou, 2004). Nanomaterials are only just becoming industrialized, meaning that humans and the environment are exposed at low concentrations and only in certain parts of the world. If some nanomaterials become broadly used, then the risk analysis changes. “Longer term, there is the opportunity for a much wider exposure of the entire ecosystem to engineered nanomaterials through the water and soil. If engineered-nanomaterial applications develop as projected, the increasing concentrations of nanomaterials in groundwater and soil may present the most significant exposure avenues for assessing environmental risk” (Colvin, 2003). It is naïve to consider that nanomaterials will both have powerful abilities to clean water and kill pathogens but cause no unintended effects. Their very application in agriculture will directly introduce them into ground and surface water catchments where they may accumulate into concentrations that may undermine the goals of food safety and environmental sustainability. Their successful integration into society will require that they not only demonstrate efficacy, but that an increasing sceptical society to be assured that the nanomaterials have been thoroughly and thoughtfully evaluated for effects on human health and the environment. In addition, their adoption could also be self-limiting if the current maldistribution in IPR is not addressed (ETC Group, 2005).

6.2.1.4 Small scale diversified farming systems.

The vast majority of the hungry, more than 90%, are suffering from chronic undernourishment. This includes a large number of smallholder farming households that are unable to grow enough food to meet their families' food requirement, or generate the income to buy sufficient food (Millennium Project Hunger Task Force, 2005). Poor farmers' needs for stable food supply are most likely to be addressed through diversified and sustainable production systems; they will therefore be part of the strategy for achieving global food security (Parrot and Marsden, 2002; Pretty and Hine 2001). Small-scale diversified farming system are able to provide the poor with a sufficient variety of food containing the necessary mix of protein, carbohydrate and fat, together with vitamins and minerals, for a healthy diet; and an appropriate quantity and diversity throughout the year, particularly during months of shortage or insecurity (Hazell and Haddad 2001b

AKST investments in small-scale, diversified farming have the potential to address poverty and equity (especially if emphasis is put on income-generation, value-adding and participation in value chains), improve nutrition (both in terms of quantity and quality through a diversified production portfolio) and conserve agro-biodiversity. In small-scale farming, AKST can build on rich local knowledge. Understanding the agro-ecology of these systems will be key to optimizing them. The challenges will be to: (1) to come up with innovations that are both economically viable and ecologically sustainable (that conserve the natural resource base of agricultural and non-agricultural ecosystems); (2) develop affordable approaches that integrate local, farmer-based innovation systems with formal research; (3) respond to social changes such as the feminization of agriculture and the reduction of the agricultural work force in general by pandemics and the exodus of the young with their profound implications for decision making and labor availability.

To solve the complex, interlinked problems of small farmers in diverse circumstances, AKST will have to make each time a conscious effort to develop a range of options. There will be hardly any “one-size-fits-all” solutions (Stoop and Hart, 2006; Franzel et al., 2004; Nkonya et al., 2004). It is questionable if AKST will have the capacity to respond to the multiple needs of small-scale diversified farming systems.

Option: Develop AKST options that combine short-term productivity benefits for farmers with long-term preservation of the resource base for agriculture (Douthwaite et al., 2002; Welches and Cherrett 2002). In small-scale, diversified farming systems, suitable technologies are typically highly site-specific (Stoop and Hart, 2006) and systems improvements need to be developed locally, in response to diverse contexts.
In the past, a distinction was made between step-wise improvements of individual elements of farming systems and “new farming systems design”. Stepwise improvement has had more impact (Mettrick, 1993), as it can easily build on local knowledge. Recently, successful innovations of more complex nature were developed, often by farming communities or with strong involvement of farmers. Examples include success cases of Integrated Pest Management (subchapter 6.4.3) as well alternative ways of land management such as the herbicide-based no-till systems of South America (Ekboir, 2003), the mechanized chop-and-mulch system in Brazil (Denich et al., 2004) or the Quesungual slash-and-mulch systems in Honduras (FAO, 2005; Welches et al., 2006).

Assessment: Small-scale diversified farming is responsible for the lion’s share of agriculture globally. While several developing country economies presently experience high economic growth rates, many of the low-income countries have moderate to low economic growth and hence will continue to depend on agriculture for employment and livelihood. The majority of poor people live in rural areas (IFAD, 2001). However, small-scale farming is increasingly becoming a part-time activity, as households diversify into off-farm activities (Ashley and Maxwell, 2001; WDR, 2000). AKST has to take this development into account when developing technologies and strategies for this target group.

While productivity increases may be achieved faster in high input, large scale, specialized farming systems, greatest scope for improving livelihood and equity exist in small-scale, diversified production systems in developing countries. About 60% of global agriculture is carried out by smallholders, who are responsible for 80% of food production in developing countries (Cosgrove and Rijsberman, 2000). As Toumlin and Guèye (2003) point out for West Africa, this family farming sector is highly dynamic, and has been responding readily to changes in natural and socio-economic circumstances through shifts in their production portfolio, and specifically to increased demand by increasing aggregate farm output. Small farmers maximize return on land, make efficient decisions, innovate continuously and cause less damage to the environment than large farms (Ashley and Maxwell, 2001). Yet they are less efficient in procuring (inputs) and marketing, especially in the face of new requirements regarding produce quality. Land productivity of small farms was found to be considerably higher than in large ones in a comparison across six low-income countries (IFAD, 2001).

In the future, research addressing single problems will probably become less relevant, as the respective opportunities for simple, one-factor improvements have been widely exploited already. New technologies will likely be more complex (addressing several factors simultaneously as in the above examples) and therefore more context and site specific and more information-intensive. Two thirds of the rural poor make their living in less favored areas (IFAD, 2001). They will continue to depend on agriculture. Returns on investment in AKST may be limited in these areas due to their inherent disadvantages (remoteness, low-fertility soils, climatic risks) and the highly diverse systems (Maxwell et al., 2001). On the other hand, impact of innovations on poverty, equity and environmental health may be substantial here. Recent examples show that improvements are possible in less favored areas, both for simple technological changes (e.g. more productive crop varieties, see 6.4.1) as well as for more complex innovations (e.g., the Mucuna cover crop system or the slash-and-mulch system in Honduras).

This will ask for a change of emphasis in research for farming system optimization. Research needs to develop decision support tools that assist extension workers and farmers in optimizing specific farm enterprises. Such tools already exist for farm economics, site-specific nutrient management, crop protection and land use planning (). Integrative approaches such as RISE (Response Inducing Sustainability Evaluation; Häni et al., 2003), which combine economic, social and ecological aspects, aim at assessing and improving sustainability at farm level.

<u>Option:</u> Develop alternatives to shifting cultivation and manage their introduction. Shifting cultivation was the most widespread form of land use in the tropics and sub-tropics, but over

the past decades, a transition occurred to managed fallows or continuous cropping with crop rotation in densely populated areas. Alternatives to slash-and-burn clearing have been developed, which better conserve the organic matter accumulated during the fallow periods.

Assessment: Managed fallows and sound rotations may enhance soil fertility regeneration and even produce additional benefits. This allows for extending cropping periods and reducing fallow periods without compromising sustainability. The resulting "offshoots" of shifting cultivation raise a number of issues to be addressed by AKST. Firstly, it will be important to understand the transition process, its drivers and the newly emerging problems in order to assist farmers (Welchez et al., 2006). Secondly, for targeted up-scaling of local experiences, it will be crucial to examine the potentials and limitations of different offshoots of shifting cultivation (Franzel et al., 2004).

Option: Low external input technologies. In less favored areas, low external input agriculture is the rule, as in these circumstances the use of mineral fertilizers and pesticides is risky and only profitable in selected cases (e.g. in high value crops). Most of the successful innovations developed for these areas built strongly on local knowledge. New low external input technologies can improve productivity and conserve the natural resource base, but there is no evidence that they are specifically pro-poor (Tripp, 2006).

Assessment: Due to site specificity of these innovations, transfer to other unfavorable environments has worked only to a very limited extent (Stoop et al., 2002). The challenge for AKST will be to find ways for combining local knowledge with innovations developed in similar other contexts to generate locally adapted new options. The question development agents will have to address is, under which circumstances they may scale up innovations and when they should focus on scaling up innovation processes (Franzel et al., 2004). In the scaling-up process, research and extension need to act in a careful, empirical and critical way (Tripp, 2006). In the past, many development efforts attempted to widely disseminate innovations that were successful in a certain context, thus creating exaggerated expectations, only to realize that these innovations were in many contexts not adapted. Examples include alley cropping (Radersma et al., 2004; Swinkels and Franzel, 2000; Akyeampong and Hitimana, 1996; Carter, 1995) or the system of rice intensification (SRI) developed in Madagascar (Stoop et al. 2002). On the other hand, Stoop (2002) concluded that agricultural research and extension still largely work with technologies that rely strongly on external inputs, even in less favored areas. Potential for innovation in low external input agriculture thus appears to exist, if research focuses on understanding and building on local concepts of farming such as the exploitation of within-farm variation, intercropping (Stoop, 2002). However, a further challenge is the dissemination, as farmer-to-farmer diffusion is less important than commonly assumed for such innovations (Tripp, 2006).

Low External Input Sustainable Agriculture (LEISA) comprises organic farming and eco-agriculture (as a framework for linking farming with landscape scale improvements for sustained or enhanced ecosystems services). Organic farming and conventional (non-labeled) LEISA can mutually benefit from each other. Organic farming with its stringent rules on external input use has to be even more innovative to solve production problems, sometimes opening up new avenues. Organic farming has the additional opportunity of deriving benefits from close links between producers and consumers. The challenge, however, is to exploit this potential. An important concern in low external input farming is soil nutrient depletion. Across Africa, nutrient depletion is widespread, with average annual rates of 22 kg of nitrogen, 2.5 kg of phosphorus and 15 kg of potassium per ha of arable land (Stoorvogel and Smaling, 1990). Low external input technologies aiming at soil fertility improvement can hardly reduce these rates (Onduru et al., 2006).

<u>Option:</u> Land use intensification. Productivity of farming systems can be enhanced by more intensive use of space and time. Intercropping (including relay intercropping and agroforestry) is an indigenous form of such intensification, widespread in food production in low-income countries, especially in less favored areas. Growing several crops or intercrops in sequence within a year offers the possibility to intensify land use in time. This intensification was made possible by changes in the crops and varieties grown (day-length-neutral or short-season varieties; varieties tolerant to adverse climatic conditions at the beginning or the end of the growing season) or in land management (no-till farming, direct seeding etc.). On the other hand, farmers quickly change to simpler cropping systems, if economic prospects are promising (Abdoellah, 2006).

<u>Assessment</u>: AKST was crucial to understand farmers' rationale for intercropping and the mechanisms making intercropping more resource-efficient and resilient than sole copping. But

formal research was often overwhelmed by the complexity of interactions occurring in a typical intercropping situation (Richards, 1985). Most important contributions of AKST were in the development of new elements (crops or crop varieties, pest and land management options) which farmers then integrated according to a multitude of criteria into their farm systems. Similarly, agroforestry initiatives were most successful, where research concentrated in developing together with farmers a range of options (Franzel et al., 2004) for farmers to add to their system.

The challenge for AKST will be to strike a balance between a) understanding the interactions in highly complex intercropping and agroforestry systems (including learning from and with farmers) and b) developing options that farmers may add at their on criteria to their systems. Adding new elements may offer potential for farmers to participate in value chains and enhance income generation while ensuring subsistence. There exists considerable potential for AKST to develop germplasm of agroforestry species with commercial value (Franzel et al., 2004).

AKST has contributed substantially to intensification in time. It was most successful in high-potential areas. But double or triple cropping in rice or rice-wheat production created new challenges on the most fertile soils (Timsina and Connor, 2001). In spite of such drawbacks, there is promise for further intensifying land use in time by optimizing rotation management and developing novel varieties that can cope with adverse conditions.

Option: Mixed farming. In many low-income countries, integration of crop and livestock has advanced substantially for the past few decades. In densely populated areas, mixed farming systems have evolved, where virtually all agricultural by-products are transformed by animals (Toumlin and Guèye, 2003).

Assessment: With the demand for livestock products expected to surge in most low-income countries (see subchapter 6.4.2.2), potential for income generation exist. A major challenge for AKST will be to understand the trade-offs between residue use for livestock or soil fertility and to optimize nutrient cycling in mixed systems.

6.2.1.5 Protected cultivation systems.

Options: Several promising AKST options (involving several actors in the value chain) are possible. Improving plastic films: Research aims at improving radiation transmission both, quantitatively and qualitatively, as well as other functions of the plastic films: In multi-layer, long-life, thermal polyethylene films, the desirable characteristics of various materials may be combined (anti-drop, diffusing direct radiation, high PAR transmission, anti-dust, UV absorption, high IR absorption). Photoselective plastic films have the potential to influence disease and insect pest behavior by blocking certain bands of the solar radiation spectrum (Papadakis et al., 2000). New plastic films limiting solar heating without reducing light transmission are being developed (Verlodt and Vershaeren, 2000).

Developing cultivars resistant to biotic and abiotic stresses: Protected cultivation has its own, specific pest and disease populations as well as specific challenges related climate and substrate. Plant breeding for these specific conditions has been initiated and has the potential to reduce significantly the amount of pollutants released, while improving productivity.

Grafting: Grafting vegetables onto resistant rootstocks is a promising option to control soil-borne pathogens (Edelstein and Ben-Hur, 2006; Bletsos, 2005; Oda, 1999) and may help to address salt and low temperature stress (Edelstein, 2004), but needs further research to improve rootstocks. It could be especially interesting for low-income countries.

Soil disinfection: Solarization has become more important as the use of methyl bromide for soil disinfection was restricted and to reduce the use of chemicals for the control of soil-borne diseases in general. But often, solarization needs to be combined with other control measures.

Pest and disease control with the use of antagonist organism: There is potential to develop bio-control agents for the specific conditions, challenges and opportunities of protected cultivation.

Improving water and nutrient management: To address the concerns of water scarcity and quality, there is a need to develop simple, low-cost systems for water and fertilizer management, which meet the possibilities of the growers and the expectations of consumers regarding produce safety and quality, are adapted to the socio-economic context and minimize environmental impacts. Innovation and tool development is needed. These systems may include soilless culture.

Process and product certification: “Quality” is the new prerequisite for any current and future market strategy.

Assessment: Protected cultivation of high value crops has expanded quickly in the past decades (Castilla et al., 2004), especially in the Mediterranean basin (Box 6.1). Production in low-cost greenhouses has the potential to increase productivity and income generation and to improve water use efficiency and reduce pollution of the environment. At present, however, greenhouse production with limited climate control is ecologically unsustainable as it produces plastic waste and contaminates water due to intensive use of pesticides and fertilizers (Stanghellini et al., 2003). Demand for innovation thus exists with regard to reducing environmental impact, as well as enhancing productivity, product quality and diversity.

Box 6.1. Mediterranean greenhouse agrosystem represents greenhouse production in mild winter climate areas and is characterized by low technological and energy inputs (Baille, 2001). Strong dependence of the greenhouse microclimate on external conditions (La Malfa and Leonardi, 2001) limits yield potential, product quality, and the timing of production. But it keeps production costs low as compared to the northern European greenhouse industry. The latter is based on sophisticated structures, with high technological and energy inputs that require important investments, and produces higher yields at higher costs (Castilla et al. 2004).

All of these options have the potential to improve sustainability. However the socio-economic context and the variability of climatic conditions in low-cost protected cultivation require the development of context-specific solutions.

6.2.1.6 Challenge: Poverty alleviation in communities with falling populations due to increased prevalence of HIV/AIDS in relation to agricultural labor.

Because of the losses associated with HIV/AIDS effects, there is need for development of agricultural technology and systems that require less labor and use fewer purchased inputs while still supporting sustainable livelihoods. There is also urgency in developing ways that allow for agricultural information and knowledge exchange between experienced farmers and young people and widows (Peter et. al., 2001-2002).

Option: Develop labor saving agricultural technologies and systems that ensure access to diverse diets.

Assessment: Agroforestry activities, such as woodlots which require less labor per unit land or processing of indigenous tree fruits, can provide income that is sensitive to labor demands (Swallow, 2003). Switching from production of more labor intensive to less labor intensive crops that need fewer inputs, such as cassava, can help households allocate labor more efficiently in food producing activities (Ngwira et al., 2001). Conservation farming techniques may become an option for many areas (Thom et al, 2004). More research is needed on labor saving agroforestry and agricultural technologies (Ngwira et al., 2001; Agumya, 2001). While diversifying food crop production to reduce labor demands can be helpful, the nutritional quality of the total diet must be considered. In the example of cassava, a B-carotene biofortified variety with the appropriate agronomic characteristics may be a more nutritious option than conventional white cassava varieties.

6.2.2 Multifunctional agriculture and ecosystem services

Ecosystem services are the conditions and processes through which natural ecosystems sustain and fulfil human life Daily (1997) and can be classified in four utilitarian functional groups: a) provisioning (e.g. food, freshwater), b) regulating (e.g. climate and disturb regulation), c) cultural (e.g. recreation, aesthetic) and d) supporting (e.g. soil formation, nutrient cycling) (MEA, 2004). Given that many ecosystem services are literally irreplaceable, estimations of socio-economic benefits and costs of agriculture should incorporate the value of ecosystem services (Costanza et al., 1997).

6.2.2.1 Challenge: How can AKST reduce the negative impact on ecosystem services.

Because of the rapid expansion of agriculture on natural lands (woodlands, grasslands) and the trend to use more external inputs (Tilman et al., 2002; Hails, 2002), the negative impact of agriculture on ecosystem services supply will require increasing attention in the coming 20 years (Rounsevell et al., 2005). With the increasing pressure on land, policy- and decision-makers would need to monitor land-use changes and drive them in response to society needs.

Option: Trade-offs analysis to assess dynamic relations between the provision of ecosystem and economic services in conflicting areas is a promising policy-oriented approach that can help to harmonize land-use options and prevent potential conflict regarding the access to essential ecosystem services (Viglizzo and Frank, 2006). Methods are focused on the identification of trade-offs and critical thresholds between the value of economic and ecological services in response to different typologies of human intervention.

Option: Designing multi-functional agricultural systems is today a sensible option to preserve and strength a sustainable flow of ecosystem services that are essential to human well-being (Vereijken, 2002). The construction of multi-functional agro-ecosystems by combining food production with the provision of other ecosystem services should be based on designs that resemble structural and functional attributes of natural ecosystems (Costanza et al., 1997). Multi-functional agro-ecosystems will provide food and fibre, control disturbances (e.g. flood prevention), supply freshwater (filtration and storage), protect soil (erosion control), cycle nutrients (nutrient balance), treat wastes (degrade organic and inorganic wastes), pollinate plants (through insects, birds and bats), control pests and diseases (through organisms), provide habitat (refugium and nursery), provide aesthetic and recreation (camping, fishing, viewing) and culture (historical costumes, artistic and spiritual information).

Assessment: The evaluation of ecosystem services is an evolving discipline that has methodological shortcomings nowadays. There is a controversy about the use and potential abuse of ecosystem values and prices. However, methods are improving soon and site-specific valuation will be possible in the coming years. On the other hand, the application of trade-offs analysis to support the design of multi-functional rural landscapes will demand expertise on multi-criteria analysis and participatory approaches to get an agreement between different stakeholders and users that have competing interests on land-use.

6.2.2.2 Challenge: Introduce multi-functional agricultural schemes to improve food security and well being in developing countries.

Many studies have demonstrated that this is possible (Parrot and Marsden 2002) and it is relevant because 60 percent of global agriculture is carried out by smallholders, who are responsible for 80 percent of food production in developing countries (Cosgove and Rijsberman, 2000) and depend on the maintenance of their life-support systems. Although its potential benefit is increasingly recognized in many developed countries (European Commission, 2001; Vereijken, 2002), most developing economies that still depend on agricultural production have not embraced the notion of multi-functional agro-ecosystems.

Option: develop land use strategies to supply ecosystem services. Frequently recommended measures (Nickel, 1973; Wayne, 1987; Viglizzo and Roberto, 1998) for addressing multi-functional needs include a) the diversification of farming activities in time and space rotational schemes, b) the incorporation of agro-forestry options, c) the preservation / conservation / rehabilitation of habitat for wildlife, d) the preservation / conservation / management of local water resources, f) the enforcement of natural nutrient flows and cycles (exploiting biological fixation and bio-fertilizers), g) the incorporation of perennial crop species, h) the well-balanced use of external inputs (fertilizers and pesticides), i) the application of conservation tillage, j) the biological control of plagues and diseases, k) the integrated management of pests, l) conservation and utilization of wild and under-utilised species, m) small-scale aquaculture, n) rainfall water harvesting.

Assessment: The loss of ecosystem services can negatively impact on IAASTD goals about hunger and poverty, nutrition and health, livelihoods and environmental sustainability. Hunger and poverty can be exacerbated by the high dependence of simplified agricultural systems on external inputs that may not be accessible to poor farmers. Poverty, hunger and the loss of feeding diversity trigger two linked problems: malnutrition and health problems. Health can also be affected by overuse and contamination of water source. Likewise, biodiversity losses plus over-exploitation of land and water resources reduce livelihoods from the life-support system and the long-term sustainability of multiple ecosystem functions. Frequent limitations and barriers to overcome in multi-functional agriculture in developing countries arise from i) cultural pre-conditioning, ii) lack of knowledge about functions and services that provide local biomes and ecosystems, (iii) national policies that ignore essential ecological functions, iv) failure in media communication, v) commercial strategies that boost the use of standardised technology and vi) the spread of homogeneous production systems and methods.

6.2.2.3 Challenge: Develop AKST to provide a constant flow of ecosystem services in the rural environment.

Option: At local, regional and trans-national scales (Dumanski et al., 1998) where different policy- and decision-makers operate, recommended measures to construct multi-functional rural landscapes (MEA, 2005) include a) the construction of diversified landscape mosaics, b) the cross-scale integration of strategies for pest management, c) the construction biodiversity corridors, d) the application of common strategies for managing shared fragile ecosystems and basins, f) the preservation of shared water sources, g) the control of bio-geochemical cycles (through the orchestrated management of rural lands).

Option: Establish the ecological-service supplier as a new category of rural producer. Such suppliers would set aside conventional commercial production schemes in order to deliver a constant and unambiguous supply of ecological services essential for human well-being in rural areas. In compensation, they must receive public recognition and payment from communities and societies that get a tangible benefit from his service (Vereijken, 2002).

Assessment: Historical trends in agricultural landscapes in developed countries, and recent trends in developing countries show: i) predominance of monoculture and poorly diversified agricultural systems, ii) production methods that depend heavily on external inputs, iii) over-stocking and over-grazing of rangelands, iv) over-cropping of fragile lands, v) loss of habitats and local bio-diversity, vi) over-use and contamination of water sources, vii) pest and disease spreading, viii) loss of indigenous knowledge. More expertise to use system approaches involving hierarchical views is demanded, especially in developing countries, to assess cross-scale problems and challenges. International cooperation is needed to share scientific knowledge and technology.

6.2.3 Post harvest and food supply chain

6.2.3.1 Challenge: Reduction of post-harvest losses.

Although reduction of post harvest losses has been an important focus of AKST and development programs in the past, in many cases the technical innovations faced socio-cultural or socio-economic problems like low profit margins, additional workload or incompatibility with the existing production or post-production system (Bell et al., 1999). The divergence between technical recommendations and the realities of rural life translated in many cases into a low adoption rates.

In specific cases, large shares of food produced is lost after harvest ( ). Yet, the rationale for improvements in the post-harvest systems has been shifting from loss prevention (Kader, 2005) to opening new markets opportunities. Making markets work for the poor (Ferrand et al., 2004) is emerging as the new rationale of development, reflecting a shift away from governmental operation of postharvest tasks to enabling frameworks for private sector initiatives in this field (Bell et al. 1999).

Option: Value chains. Increasing interest is emerging to look at entire value chains. Value chain analysis, up-grading and innovation are receiving more attention (Kaplinski, 2002). Processing, transport and marketing of agricultural products are increasingly seen as a vertical integration process form producers to retailers to reduce transaction costs and improve food quality and safety (Chowdhuri et al., 2005).

Assessment: Demand driven production asks for improved market literacy of producers, a challenge especially for smallholders, but is a prerequisite for access to supermarkets (Reardon et al, 2004; Hellin et al, 2005).

Building trust among the stakeholders in the market chain is a crucial component of vertical integration (Best et al., 2005; Chowdhury et al., 2005; Guliani et al., 2005). It enhances transparency of the market chain and exchange of information. Typically, actors in the market chains are at first skeptical about information sharing, and only when they realize that all can benefit from more transparency along the market chain readily provide information.

Maximizing added value at farm or village level is a promising option for small farmers to reap the benefits from upcoming opportunities in value chains. The development of rural agro-enterprises or household level processing can increase income generation in rural areas (Best, 2005 et al.; Guiliani et al., 2005).

Focusing on value chains can make a difference for small farmers (Guiliani et al, 2005, Bernet et al, 2005, Best et al, 2005). Better market access is often a key concern for small farmers (Bernet, 2005) as a way to increase cash income. Crops neglected so far by formal research and extension constitute a potential for up-grading value chains (Guiliani et al., 2005; Hellin and Highman, 2005; Gruère et al., 2006) in which small farmers have a comparative advantage. Thus, AKST investments in value chain research have the potential to improve equity by opening up income opportunities for small farmers. The challenges will be to find ways for making small farmers competitive, to identify opportunities and develop value chains which build on their potential (labor availability, high flexibility). Increasing requirements of the market regarding food quality, safety and trackability will limit small farmer participation in certain value chains. Further, access to market may be limited by inadequacies of (road system, refrigerated transport and storage etc.).

Successes in value chain development have been achieved through extensive consultation processes among all actors such as in the "participatory market chain approach" (Bernet et al, 2005). Costs and benefits of such approaches will have to be carefully assessed to see, in which type of value chains such AKST investment is justified. Especially for niche products with limited market volume, investments for up-grading the market chain could be high compared with potential benefits.

6.2.4 Reduced dependence on fossil fuel energy inputs

Need text from someone

6.2.5 Bioenergy

6.2.5.1 Challenge: How can the production of biofuels contribute to supporting rural development and job creation?

Option: Promotion of the domestic production of 1st generation biofuels and agricultural feedstocks. Domestic production of liquid biofuels that rely on the cultivation of agricultural crops, is often credited with positive externalities for rural development through creating new sources of income and jobs in feedstock production and energy conversion industries (e.g. Moreira and Goldemberg, 1999; von Braun and Pachauri, 2006; Worldwatch Institute, 2006). However, the actual effect of bioenergy on rural economies is complex and has strong implications for income distribution, poverty and food security. Careful analyses at the local level are needed to assess potential benefits and costs.

Economically, the major impact of biofuels production is the increase in demand for energy crops. In fact, biofuels have historically been introduced as a means to counteract weak demand or overproduction of feedstock corps, e.g. this was a principal reason for Brazil to introduce its ProAlcool Program in 1975 (Moreira and Goldemberg, 1999). On the one hand, this additional demand can increase incomes of agricultural producers and the increased local economic activity in rural communities may induce dynamic processes of social and economic development (Coelho and Goldemberg, 2004; DOE, 2005; FAO, 2000; Worldwatch Institute, 2006). On the other hand, even if biofuels can be produced competitively, at least part of the rise in agricultural incomes represents a mere redistribution from consumers of agricultural products to producers. In fact, rising demand for agricultural products can lead to increases in food prices (see chapter 4). Second, when biofuels are promoted despite their higher costs, an analogous redistribution from energy consumers to agricultural producers takes place. In both cases the effects on poverty are highly complex. Some rural poor may gain if they can participate in the energy crop production process or otherwise benefit from increased economic activity in rural areas. This depends critically on production methods (e.g. degree of mechanization) and institutional arrangements (e.g. structure of the agricultural sector and property rights of agricultural land). Conversely, those rural and urban poor people who spend a considerable share of their incomes on energy and especially food are bound to lose dramatically from rising prices. The same applies for food-importing developing countries who would suffer severely under globally rising food prices.

Biofuels are considerably more labor intensive in production than other forms of energy such as fossil fuels (Goldemberg, 2004). However, estimating their actual employment impacts is highly complex. First, any newly created employment needs to be weighed against jobs that are displaced in other sectors. This includes jobs that may be lost in other energy industries or jobs that would have been created in the feedstock production sector even in the absence of biofuels production, e.g. in sugar production. These dynamics are complex and may involve very different industries, e.g. the livestock industry which is a major user of agricultural crops as fodder (Centre for International Economics, 2005). Also small-holders or landless peasants who may be displaced need to be included into this analysis. Second, while bioenergy is labor intensive compared to other energy industries, it is not necessarily labor intensive compared to other forms of farming. In fact, energy crop production very often takes the form of large-scale mechanized farming in order to produce biofuels competitively. Thus, in cases where traditional farming is replaced by less labor intensive energy crop production, jobs may actually be lost. Similarly, no new jobs are created if biofuels production simply displaces other agricultural crops. In such cases there further arises the question of whether job substitution is actually beneficial, especially considering that many jobs in feedstock production are temporary and seasonal (Fritsche et al., 2005; Kojima and Johnson, 2005; Worldwatch Institute, 2006). More research is needed to assess the magnitude of potential rises in food prices and the social and economic dynamics of expanding 1st generation biofuels production.

6.2.5.2 Challenge: What are the options for developing liquid biofuels for transport that are economically viable and socially and environmentally sustainable?

Current trends indicate that a large-scale expansion of production of 1st generation biofuels for transport will create huge demands on agricultural land and water – causing potentially devastating effects for food prices and the environment (see chapter 4).

Option: Reducing land requirements through increasing yields of agricultural feedstocks. Efforts are currently focused on increasing biofuel yields per hectare while reducing agricultural input requirements by optimizing cropping methods or breeding higher yielding crops. For example, Brazil has been able to increase yields and reduce crop vulnerability to drought and pests by developing more than 550 different varieties of sugar cane, each adapted to different local climates, rainfall patterns and diseases (GTZ, 2005). Both conventional breeding and genetic engineering are being employed to further enhance crop characteristics such as starch or oil content to increase their value as energy crops. Many crops in developing countries are believed to be prone to larger increases in yields but more research is needed to develop this potential (Cassman et al., 2006; Ortiz et al., 2006; Woods, 2006). However, even if yields can successfully be increased, several problems will persist: Total land area under cultivation will still need to expand considerably in order to meet large-scale demand for biofuels.

Economic competitiveness will continue to be an issue, considering that even in Brazil – the world leader in efficient ethanol production – biofuels are competitive only under particularly favorable market conditions (Kojima et al., 2007). Concerns about the employment of GMOs as well as the problematic resemblance of some biofuels feedstocks with invasive species (Raghu et al., 2006) need to be carefully assessed with special emphasis in the local context.

Option: Producing biofuels from inedible feedstock and on marginal lands.

It is often argued that using inedible energy crops for the production of biofuels would reduce pressures on food prices. Moreover, many of these crops, e.g. Jatropha, Poplar and Switchgrass, could be grown productively on marginal land, without irrigation and potentially even contributing to environmental goals such as soil restoration and preservation (GEF, 2006; IEA, 2004; Worldwatch Institute, 2006).

Inedible feedstocks: Food price increases can be caused directly, through the increase in demand for the biofuel feedstock, or indirectly, through the increase in demand for the factors of production (e.g. land and water). Thus, using non-edible plants as energy feedstocks but growing them on agricultural lands would only have a limited mitigating effect on food prices.

Marginal lands: The issue has not yet been addressed comprehensively and several risks persists that need to be analyzed more closely (i) the production of energy crops on marginal land would most probably increase biofuels production costs (due to lower yields, inefficient infrastructure, etc.), leading to low economic incentives to produce on these lands. In fact, while estimates of available marginal land are large, especially in Africa and Latin America (Faaij et. al., 2003; FAO, 2000; Worldwatch Institute, 2006), much of this land is remotely located or not currently suitable for crop production and may require large investments in irrigation and other infrastructure. (ii) Environmental effects of bringing these lands into production need to be carefully analyzed, especially with regards to soils, water resources and biodiversity.

<u>Option:</u> Development of next generation biofuels

Significant potential is believed to lie with the development of new energy conversion technologies – so-called 2nd generation or next generation biofuels. Several different technologies are being pursued, which allow the conversion into biofuels not only of the glucose and oils retrievable today but also of cellulose, hemi-cellulose and even lignin – the main building blocks of most biomass. Thereby, cheaper and more abundant feedstocks such as residues, stems and leaves of crops, straw, urban wastes, weeds and fast growing trees could be converted into biofuels (DOE, 2007; IEA, 2006; Ortiz et al., 2006; Worldwatch Institute, 2006). This could dramatically reduce land requirements – mitigating social and environmental pressures from large-scale production of 1st generation biofuels. Moreover, lifecycle GHG emissions could be further reduced, with estimates for potential reductions ranging from 51 to 92 percent compared to petroleum fuels (European Commission, 2005; Farrell et al., 2006; GEF, 2005; IEA, 2004).

The most promising 2nd generation technologies are cellulosic ethanol and biomass-to-liquids (BTL) fuels. Cellulosic ethanol is produced through complex biochemical processes by which the biomass is broken up to allow conversion into ethanol of the cellulose and hemi-cellulose. One of the most expensive production steps is the pre-treatment of the biomass that allows breaking up the cellulose and removing the lignin to make it accessible for fermentation. Research is currently focused on how to facilitate this process, e.g. through genetically engineering enzymes and crops [add cross reference]. BTL technologies are thermo-chemical processes, consisting of heating biomass – even lignin-rich residues left over from cellulosic ethanol production – under controlled conditions to produce syngas. This synthetic gas, consisting mainly of carbon monoxide and hydrogen, is then liquefied e.g. by using the Fischer-Tropsch (FT) process to produce different fuels – including very high-quality synthetic diesel, ethanol, methanol, buthanol, hydrogen and other chemicals and materials. Research is also focusing on integrating the production of 2nd generation biofuels with the production of chemicals and electricity in so-called biorefineries (Aden et al., 2002; GEF, 2006; Hamelinck and Faaij, 2006; IEA, 2004; IEA, 2006; Ledford, 2006; Ragauskas et al., 2006; Woods, 2006)

2nd generation biofuels have to overcome several critical steps in order to become a viable and economic source of transport fuels on a large scale. First, next generation biofuels technologies have not yet reached a stage of commercial maturity and significant technological challenges need to be overcome to reduce production costs. It is not yet clear when these breakthroughs will occur and what degree of cost reductions they will be able to achieve in practice (DOE, 2007; Sanderson, 2006; Sticklen, 2006). Second, even if these breakthroughs occur, biofuels will have to compete with other energy technologies that are currently being developed in response to high oil prices. For example, with regards to transport fuels, technological progress is currently reducing costs of conventional (e.g. deep sea) and unconventional (e.g. tar sands) oil production and also of coal and gas to liquid technologies. Third, while some countries like South Africa, Brazil, China and India are currently engaged in advanced domestic biofuels R&D efforts, high capital costs, large economies of scale, a high degree of technical sophistication as well as intellectual property rights issues make the production of 2nd generation biofuels problematic in the majority of developing countries even if the technological and economic hurdles can be overcome in industrialized countries.

Institutional and financial support for R&D on next generation biofuels is needed to advance their development in industrialized countries. Further research is needed to determine the practical applicability of 2nd generation biofuels in developing countries as well as possible institutional and technological adaptations to developing country needs.

6.2.5.3 Challenge: How can the production of bioenergy for local uses benefit communities and contribute to social and economic development?

Living conditions and health of the poor can be considerably improved when households have the opportunity to upgrade from inefficient, polluting and often hazardous traditional forms of biofuels to modern forms of energy. Through their importance for the delivery of basic human needs such as potable water, food and lighting, as well as for more advanced industrial applications these modern energy services are among the primary preconditions for social and economic development (Barnes and Floor, 1996; Cabraal et al., 2005; Modi et al., 2006). Modern bioenergy is one of several technology options available for advancing these goals while reducing dependence on cash purchases of energy and providing livelihood opportunities. Careful assessments of local needs, economic competitiveness as well as social and environmental effects are needed to determine under which circumstances modern bioenergy should be promoted.

Option: Development of small-scale applications of biodiesel and unrefined bio-oils

Assessment: The environmental and social costs of producing biofuels can be considerably lower in small-scale applications for local use due to contained demands on land, water and other resources. At the same time, the benefits for social and economic development may be higher, especially in remote regions, where exceptionally high transportation costs add to the delivered cost of fossil energy and thereby undermine energy access (Kojima and Johnson, 2005). Land-locked developing countries, small islands, and also remote regions within countries may fall into this category – if they can make available sufficient and cheap feedstock without threatening food security. Especially biodiesel offers potential in small-scale applications as it is less technology and capital intensive to produce than ethanol. Unrefined bio-oils offer similar benefits and their production for stationary uses such as water pumping and power generation is being analyzed in several countries, often focusing on Jatropha as a feedstock (Buchholz et al., 2005; Coelho et al., 2005; Indian Planning Commission, 2003; van Eijck and Romijn, 2006). More research is needed to assess how diesel generators can be retrofitted as to work effectively with bio-oils and on the costs and benefits to society.

Option: Development and distribution of biomass digesters and thermo-chemical options for electricity and heat generation from biomass. Some forms of bioelectricity and bioheat can be competitive with other off-grid energy options (e.g. diesel generators) and therefore are viable options for expanding energy access in certain settings. The largest potential lies with the production of bioelectricity and heat when technically mature and reliable generators have access to secure supply of cheap feedstocks and capital costs can be spread out over high average electricity demand. This is mostly the case on site or near industries that produce biomass wastes and residues and have their own steady demand for electricity, e.g. sugar, rice and paper mills. The economics as well as environmental effects are particularly favorable when operated in combined heat and power mode (IEA, 2006; WADE, 2004). More research is needed to assess this potential at regional and local levels.

Biomass digesters and gasifiers are more prone to technical failures that direct combustion facilities, especially when operated in small-scale applications without proper maintenance. More research and development is needed to improve the operational stability of these technologies as well as the design of institutional arrangements. Mixed results of past experiences as well as recent successes of programs in China, India and Nepal can offer valuable lessons in this regard (see chapter 8).

6.3 Options for Improving Nutrition and Health through AKST

6.3.1 Challenge: Improving human health and nutrition

Nutritional deficiencies undermine health and well-being and can negatively affect labor productivity. Among subsistence farmers who depend on manual labor for their livlihoods, nutritional adequacy of the diet is essential. Iron deficiency anemia is associated with over 100,000 deaths of pregnant women (ACC/SCN, 2004), and one third of the world’s population live in countries with high risk of zinc deficiency (IZiNCG, 2004). On the other hand, weight gain, hypertension, high blood cholesterol, and a lack of vegetable and fruit intake result in significant health burdens in both high and low-income countries and are emerging as causes of disease burden in low-income countries (Ezzati et al., 2002). As dietary intakes of refined carbohydrates have increased, overnutrition and its associated chronic diseases have begun to affect people throughout the developing and industrialized countries (Popkin, 2004; Johns and Eyzaguirre, 2006).

Option: Improve dietary quality through agrobiodiversity strategies and food preservation techniques. Improving crop diversity is an important part of improving dietary diversity, and thereby dietary quality. Substituting carotenoid rich red palm oil for other vegetable oils can improve vitamin A status as seen in consumers in Burkina Faso (Zagre et al., 2003). Agricultural biodiversity (agrobiodiversity) offers ways to diversify the diet. Preliminary evidence from a study in Kenya demonstrated that when rural farmers produced traditional leafy green vegetable varieties, in addition to increased consumption among farmers, the producers found a market among middle and high income consumers in Nairobi who began to purchase these novel foods (Frison et al., 2006). Increased research on locally adapted traditional varieties could lead to the development of improved varieties that are higher yielding or more resistant to pests and abiotic stresses such as drought. Researchers could increasingly use currently available analytic techniques to identify the wide range of potential health promoting compounds found in indigenous and underutilized plant foods. Once identified, plant breeders can develop varieties of these foods which can be produced and consumed by smallholder farmers as well as sold in high value niche markets of middle and upper income nationals or industrialized countries where there is increased demand for novelty health promoting products. Additionally, wild foods that are collected by subsistence farmers as part of the traditional diet could be processed at the household level to improve storability and would make additional foods available during the seasonal hungry periods. For example, solar drying techniques have been used to preserve foods such as mangoes and sweet potatoes.

Assessment: The diversity of plants, both wild and cultivated traditional varieties in rural areas of the developing world, provides many opportunities to identify high quality nutritious foods already available to, yet underutilized by, farmers. Possible improvement of these varieties through breeding is limited as private and public sector breeding programs rarely focus attention on minor crops. To benefit from the available biodiversity, it is critical that agricultural research programs focused on developing world agriculture expand their work in this area. Furthermore, preservation methods must be improved to reduce the loss of micronutrients (Ndawula et al., 2004). Thus, crop breeding research should complement research on improved storage approaches to ensure that the nutritional benefits of new crops are maintained at the household level.

Option: Increase availability and accessibility of animal source foods. In addition to increasing the range of plant foods in the diet, animal source foods (ASF), such as meat, milk, and insects from wild and domesticated sources can provide critical nutrients that may be completely unavailable in plant-based diets, such as vitamin B12, a nutrient critical for brain development (Neumann et al., 2002). Access to ASF was shown to improve serum vitamin B12 status in Kenyan school children (Siekmann et al., 2003). An effective strategy to increase the intake of animal source foods could include the identification and/or development of viable ways of home yard and small-scale livestock production. These include identification and/or development of appropriate breeds, disease prevention and control and affordable high quality animal feeds (Brown, 2003).

Assessment: Estimates indicate that by the year 2030, developing countries will contribute 66% of the world meat production and 55% of world milk production (Steinfeld, 2003). However, domination of livestock production by integrated large-scale commercial operations has the danger of displacing small-scale livestock farmers and exacerbating rural poverty and nutrition. There is need to create an environment that enables small-scale, poor and household producers to take advantage of development opportunities, productivity and trade (Steinfeld, 2003). As land availability can be a limiting factor in small-scale livestock production (Steinfeld, 2003), increased research on environmentally sustainable intensification is needed. Research is also needed on ways small-scale producers can manage livestock to meet sanitary requirements of markets as well as training to build that capacity.

Option: Improve soil quality to optimize plant nutritional quality.

Assessment: Improving soil management practices, such as increasing the organic matter in the soil and mineral fertilizers (Sheldrick and Lingard, 2004), can improve food security and enable farmers to produce sufficient yields and allow for more crop diversification. For example, crops grown on zinc deficient soils often produce grains with low zinc concentrations and these seeds may produce plants with lower grain yields and poorer seed quality (Rengel, 2001). Subsequent plantings of these crops on zinc deficient soils can lead to lower yields, decreased food security, and inadequate zinc intakes in the diet (Rengel, 2001). Improving soil can take years, and while more research is needed on methods to optimize soil fertility for the range of soil types and cropping systems in developing countries, current knowledge, such as the addition of organic matter to the soil to improve productivity, can be considered (Gruhn et al., 2000).

Option: Develop varieties of nutritionally enhanced crops.

Assessment: Biofortified crops, which are developed through plant breeding, can improve human nutrition. For the nutrients targeted in staple crop breeding programs, the nutritional status of populations consuming the staple can be improved. Biofortification has shown promise in feeding studies in the Philippines where iron biofortified rice consumption improved iron status in the study participants (Murray-Kolb et al., 2004). While conventional food fortification can work well to improve the availability of critical nutrients in the diet, rural subsistence producers may not have access to fortified foods. Thus, where food processing facilities are unavailable, biofortification can improve the availability of target nutrients. In addition, where government regulation and enforcement of food fortification is still in the nascent stages of development, biofortified crops can serve as a cost-effective source of micronutrients for all consumers. While plant breeding efforts to biofortify staple crops are underway (HarvestPlus, 2006), plant breeding programs can also target health-related qualities in the development of new fruit and vegetable varieties, such as lutein-rich carrots (Nicolle et al., 2004). Plant breeding can include both traditional techniques and/or approaches using advances in biotechnology, such as rDNA. In the case of developing crop varieties with genes from unrelated species, it must be noted that biosafety and regulatory mechanisms are still being developed in many developing countries, and it could take years for products of biotechnology to be tested and released for general production by smallholder farmers (Eicher et al., 2006). Furthermore, plant breeding, whether using traditional methods or via biotechnology, can easily take a decade to develop new crop varieties. Therefore, the range of research objectives must be considered carefully and communicated to breeders to ensure they are aware of the range of objectives to consider in breeding programs.

6.3.2 Challenge: increased prevalence of HIV/AIDS in relation to agricultural labor

Because of the losses associated with HIV/AIDS effects, there is need for development of agricultural technology and systems that require less labor and use fewer purchased inputs while still supporting sustainable livelihoods. There is also urgency in developing ways that allow for agricultural information and knowledge exchange between experienced farmers and the youth and widows (Peter et. al., 2001-2002).

<u>Option:</u> Develop labor saving agricultural technologies and systems that ensure access to diverse diets.

<u>Assessment</u>: Agroforestry activities, such as woodlots which require less labor per unit land or processing of indigenous tree fruits, can provide income that is sensitive to labor demands (Swallow, 2003). Switching from production of more labor intensive to less labor intensive crops that need fewer inputs, such as cassava, can help households allocate labor more efficiently in food producing activities (Ngwira et al., 2001). More research is needed on labor saving agroforestry and agricultural technologies (Ngwira et al., 2001; Agumya, 2001). While diversifying food crop production to reduce labor demands can be helpful, the nutritional quality of the total diet must be considered. In the example of cassava, a B-carotene biofortified variety with the appropriate agronomic characteristics may be a more nutritious option than conventional white cassava varieties.

6.3.3 Challenge: Better use of indigenous knowledge as a tool for enhancing community nutrition and healthcare

In the agricultural sector's response to malnutrition and disease, the local knowledge and resource base (particularly biodiversity and indigenous knowledge) has been notably neglected. Indigenous knowledge, if adequately promoted and upgraded, will serve to broaden community-based responses for nutrition and healthcare.

Option : advocating traditional and under-utilised crops, promoting agricultural diversification practices, improving home gardens, supporting the sustainable harvesting of wild food plants, strengthening medicinal plants' use, and establishing community seed systems. The mobilisation and improvement of these resources would be instrumental in expanding the options and means of poor rural households to enhance their nutrition and healthcare. These resources are locally available, affordable, easy to deploy, versatile and remarkably contextualised in the ecological and cultural realities of many rural communities.

Assessment: The mobilisation of local crop and plant resources could become an important strategy to strengthen grassroots responses to malnutrition and healthcare (Garí, 2004) , while strengthening their agricultural and livelihood systems: The proposed strategy would provide a wide array of tangible benefits to the nutrition/health interface of poor rural communities, especially:

- enrichment of diets, including improvement of the micronutrient intake
- optimal use of existing crop and food resources, especially when households lack access to productive resources (such as labor, land, cash or seed)
- further recognition and support for the roles of rural women in agriculture, food production and household nutrition
- preparing meals and diets that suit the conditions and needs of sick people
- enhancement of the immune system and the wellbeing of sick people
- use of medicinal plants as part of primary healthcare
- good nutrition as the first medicine for HIV/AIDS

The improved use of plant resources can contribute to the prevention of HIV (through reducing the livelihood vulnerabilities that often spread HIV/AIDS), to the care of people living with HIV/AIDS (through improved nutrition and the use of medicinal plants) and to the mitigation of the socio-economic impact of HIV/AIDS (through deploying agricultural practices that are adapted to cope with the impacts of the pandemic on the labor capacity and the economy of affected households).

6.3.4 Challenge: Emerging human and animal diseases constrain progress towards achieving development goals

Emerging infectious diseases impact both high- and low-income countries. Currently, 204 infectious diseases are considered to be emerging; 29 in livestock and 175 in humans [Taylor et al. 2001]. Of these, 75% are zoonotic (diseases transmitted between animals and humans). The number of emerging plant, animal, and human diseases will increase in the future, with pathogens that infect more than one host species more likely to emerge than those infecting single-host species [Taylor et al. 2001]. Serious socioeconomic impacts result when diseases spread widely within human or animal populations, or when they spill over from animal reservoirs to human hosts [Cleaveland et al. 2001]. Even small-scale animal disease outbreaks can have major economic impacts in pastoral communities [Rweyemamu et al. 2006].

Animal diseases not only affect animal health and welfare, they also can affect human health, influence perceptions of food safety, result in trade restrictions, adversely affect rural incomes and livelihoods, adversely affect non-livestock rural industries, have detrimental environmental effects, and adversely affect national economies for countries heavily dependent on agriculture [Rweyemamu et al. 2006]. Increasing awareness of the impacts of infectious animal diseases requires altering current strategies for disease management.

Factors driving emergence of human and animal diseases include intensification of crop and livestock systems, social factors (e.g. expansion of international trade), demographic factors (e.g. population growth), environmental factors (e.g. land use change and global climate change), and microbial evolution. Diseases will continue to emerge and re-emerge; even as control activities successfully control one disease, another will appear. Most of the factors that contributed to disease emergence will continue, if not intensify, in the 21st century [IOM 1992].

Option: Enhance surveillance and control programs. Controlling emerging infectious diseases requires early detection, through surveillance at national, regional, and international levels, and rapid intervention. For animal diseases, traceability, animal identification, and labeling also are needed. The main control methods for human and animal diseases include diagnostic tools, disease investigation facilities, and safe and effective treatments and/or vaccines. AKST under development can facilitate rapid detection of infectious pathogens. For example, genetic tools were used in recent HPAI outbreaks to identify the viruses involved and to inform development of appropriate control programs [FAO, OIE, WHO 2005]. Syndromic surveillance of farm animals coupled with notification using internet-accessible devices is being used in some high-income countries to detect emerging diseases [Vourc'h et al. 2006].

Assessment: Increasing importance of zoonotic diseases requires better integration of human and veterinary public health approaches for their detection, identification, monitoring, and control. Decreased funding in recent decades has eroded the required infrastructure and training underlying surveillance activities. There is an urgent need to replenish basic capacity in many high income countries and to increase capacity in middle- and low-income countries. Linkage of regional and international organizations and agencies is critical. Improved understanding is needed of disease transmission dynamics in order to develop more effective and efficient diagnostic systems and interventions. Diagnostic systems should be designed to process large numbers of samples and identify multiple infectious agents.

Although vaccines are a cornerstone of primary prevention, vaccine effectiveness is severely limited in remote rural areas with high infectious disease burdens, particularly Africa, South America, and Asia, due to the lack of vaccines, the lack of money to afford vaccines, or the logistical problems of trying to use temperature-sensitive vaccines. Marker vaccines are needed so that vaccinated/treated animals can be distinguished from sub-clinically infected or convalescent animals real-time during epidemics (Laddomada, 2003).

The emergence and dissemination of bacteria resistant to antimicrobial agents is the result of complex interactions among antimicrobial agents (e.g. antibiotics), microorganisms, disease transmission dynamics, and the environment (Heinemann, 1999; Heinemann et al., 2000).

The increasing incidence of antimicrobial resistant bacterial pathogens will limit future options for prevention and treatment of infectious diseases in animals and humans [McDermott et al. 2002]. The World Health Organization has called for human and veterinary antimicrobial agents to be sold only under prescription, and for the rapid phase-out of antimicrobial agents used as growth promotants (WHO 2003). They also recommended that all countries establish monitoring programs for tracking antimicrobial use and resistance. Research on the use of other treatments, such as probiotics and vaccines, holds promise (Gilchrist et al., 2007). The ongoing costs of research and development, and challenges to delivery will prevent acute drug treatments from ever being a stand alone solution.

Option: Increase adoption of integrated vector and pest management, including environmental modification, such as filling and draining small water bodies, environmental manipulation, such as alternative wetting and drying of rice fields, and reducing contacts between vectors and humans, such as using cattle in some regions to divert malaria mosquitoes from people [Mutero et al., 2004; Mutero et al., 2006].

Assessment: Specific farming practices can facilitate infectious disease emergence and reduce the incidence of certain diseases (such as malaria) in endemic regions (van der Hoek, 2004). However, the relationships between agriculture and infectious disease are not always straight-forward. For example, while rice irrigation increases breeding grounds for the mosquito that carries malaria, in some regions the prevalence of malaria in irrigated villages is lower than in surrounding villages because better socioeconomic conditions allow greater use of antimalarials and bednets [Ijumba et al. 2002] and/or because the mosquito vector tends to preferentially feed on cattle [Mutero et al. 2004]. However, in other regions, intensification of irrigated rice reduces the capacity of women to manage malaria episodes among children, leading to a higher prevalence of malaria [De Plaen et al. 2004]. Therefore, greater understanding is needed of the ecosystem and socioeconomic consequences of changes in agricultural systems and practices, and how these factors interact to alter disease risk.

6.4 Options for improving Natural Resource Management

6.4.1 Land and soil management

6.4.1.1 Challenge: Using AKST to address poor soil management and degraded soil fertility to deliver sustainable increases in productivity.

A clear finding in Chapter 3 is that the availability of land for further geographic expansion of agriculture is limited. Projections estimate that 50 to 70 % more cereal grain will be required by 2050 to feed 9.3 million people (Ladha et al., 2005). Consequently future increases in agricultural production will have to result from increased total factor productivity and the restoration of degraded land and ecosystem services. The approach will be distinctly different in fertile and marginal lands (Hartemink, 2002) and when comparing subsidized (e.g. EU, US, Japan) and non-subsidized agriculture (e.g. Australia, Canada, Argentina, Brazil, Ucrania, Egypt, South Africa, as summarized in Table 6.1.

Option: Wider adoption of best practice for enhancing soil management and fertility.

Option: for fertile lands:

- Increase nitrogen use efficiency (NUE) that is currently less than 50% worldwide (Fageria and Baligar, 2005; Ladha et al., 2005; Sommer et al., 2004), y using crop models (Alvarez, 2005) or soil nitrogen tests for adjusting fertilizer rates (Delgado and Bausch, 2005; Francis, 2005). In areas with polluted groundwater, nitrate uptake by deep rooting crops could potentially serve to redistribute N for crops (Berntsen et al., 2006).

- Development and adoption of precision agriculture (PA) such as variable rate technologies will allow farmers to vary inputs, such as fertilizers, pesticides and seeding rates throughout fields based on management zones (Adrian et al., 2005).
- Substitution of phosphorus (P) sources, by adopting P recycling by agricultural by products and biosolids (Edwards et al., 2002; Kashmanian et al., 2002); or the use of P-solubilising bacteria (Taradfar and Claassen, 2005; Yadav and Tarafdar, 2001), and a more widespread use of arbuscular mycorrhizal fungi (Harrier and Watson, 2003).
- Alleviation of deep reaching soil compaction by controlling traffic in the fields (Pagliai et al., 2004; Spoor, 2006; Spoor et al., 2003), sowing cover crop root channels, and/or ploughing (Robson et al., 2002; Spoor et al., 2003).

Assessment: Fertilizers and other inputs (e.g. pesticides) have to be dosed in relation to the overall environmental demands, synchronizing N supply with crop demand (Fageria and Baligar, 2005; Francis, 2005). Crop models aim to explore management options resulting in increased yield, and to determine trade-off between yield, resource-use efficiency and environmental outcomes (Timsina and Humphreys, 2006). Their effective adoption requires improved farmer's knowledge and cost-effective and user friendly techniques (Ladha et al., 2005). In a similar way, the adoption of PA by farmers is significantly affected by their perception of its usefulness and net benefit (Adrian et al., 2005). Motivations for widespread uptake adoption of PA technologies may come from strict environmental legislation, public concern over excessive use of agrochemicals, and efficiency (Zhang et al., 2002). The existing technological gap between developed and developing countries represents a barrier limiting the adoption of modern agricultural technologies. Therefore, action will need to be supplemented by government and international sources, to provide technical advice, economic incentives and public education programs.

Some controversy arises when analyzing world resources of inexpensive P: according to Vance et al. (2003). They may be depleted by 2050. However, the Potash and Phosphate Institute (PPI) clearly disagrees with this worrying scenario. World reserves of phosphate rock in conditions to be economically exploited under the present economic and technological conditions are 50 billons tons, while present exploitation only reaches 138 million tons (Dick, 2004).

Option: for fertile lands with non subsidized agriculture

- increase fertilization rates by increasing crop nutrient demand.
- Adoption of zero tillage to prevent further water erosion losses, sequester organic carbon in soils, and maintain a good topsoil structural condition (Bolliger et al., 2006; Díaz Zorita et al., 2002; Lal et al., 2007; Steinbach and Alvarez, 2006).
- Adoption of soil erosion control practices, such as contour cropping and terracing in soils of better quality (Popp et al. 2002) and growing cover crops (Lal 2001).
- Increasing botanical nitrogen-fixation may be achieved by break crops to avoid the continuous cropping of cereals (Robson et al., 2002) and green manure crops improve the N supply for succeeding crops (Thorup-Kristensen et al., 2003).
- In farms near animal production facilities (feed lots, poultry, pigs, dairy, etc.), organic animal manures may be a cheap source of essential plant nutrients and organic carbon reposition to soil (Edwards and Someshwar, 2000; Robson et al., 2002).

Assessment: ZT exerts well known positive effects upon soil properties. However, some negative effects must be also considered. Greenhouse gas emissions (N_2O, CH_4) can either increase or decrease after the adoption of zero tillage (Baggs et al. 2003, Dalal et al. 2003, Omonode tet al. 2007, Passianoto et al. 2003, Six et al. 2004, Steinbach and Alvarez 2006). ZT can promote shallow compaction in fine textured topsoils (Díaz Zorita et al., 2002; Sasal et al., 2006, Taboada et al., 1998). No-till farming can reduce yield in poorly drained, clayey soils when springtime is cold and wet. Soil-specific research is needed to enhance applicability of no-till farming by alleviating biophysical, economic, social and cultural constraints (Lal et al. 2007).

Soil erosion control is costly, and hence, difficult to implement in developing countries (Wheaton and Monke, 2001). Local planning and action might be supplemented by government provision of free technical advice, economic incentives and public education programs (Warkentin, 2001).
Key farm/pasture management strategies identified to optimize N_2 fixation in legume-based pastures include selecting suitable legume and grass cultivars, restricting grazing intervals,

altering seasonal grazing intensity, use of mixed animal types, strategic conservation cuts, and a management to reduce soil physical damage (Menneer et al., 2004; Sims et al., 2005). The use of organic manures can be limited by problems associated with storage, handling, and transport (Edwards and Someshwar, 2000) For many agricultural by products benefits are not clearly demonstrated, and their unscrupulous use has the potential to seriously contaminate fields of naïve or unquestioning land owners (Miller et al., 2000).

Option: for marginal lands small-scale approaches based on agroecology, agroforestry and the use of organic manures.

- Replacement of traditional slash and burn cultivation by more diversified production systems, based on forest products, orchard products, and forages and food products (Barrett et al., 2001; Ponsioen et al., 2006; Smaling and Dixon, 2006). Agroecological principles must be applied creatively within each particular agroecosystem (Altieri, 2002; Dalgaard et al., 2003).
- Adoption of agroforestry to maintain land productivity, decrease land degradation, and improve rural people's livelihood (Albrecht, 2003; Jiambo, 2006; Oelberman et al., 2004; Rasul and Thapa, 2006; Reyes et al., 2005; Schroth et al., 2004).
- Water conservation is key. Soil management must be focused on crops with increased water use efficiency, and suitable crop sequences adapted to available rain water. Conservation tillage, mulching, fallowing can be adopted by the farmers to increase soil water storage.

Adoption of (i) supplemental irrigation for optimizing the use of the limited water available from renewable resources in rainfed areas, and (ii) water harvesting for improved farmer income in drier environment (Goel and Kumar, 2005; Hatibu et al., 2006; Oweis and Hachum, 2006). C4: Adoption of practices like green manuring, composting, farm-yard manure management, optimal use of agricultural by-products and residues, to be dealt with in a context-based and site-specific manner.

Assessment: Effectiveness of agroecology must not be overestimated, taking into account the negative effects often found in N and P availability with alley cropping (Radersma et al., 2004) and the fact that consecutive nutrient exports may lead to extremely low potassium and phosphorus levels (Alfaia et al., 2004). Ecological agriculture could become an alternative if market distortions created by subsidies were removed, and financial benefits were provided to resource-conserving farmers along with necessary support through extension, credit, research, and marketing. (Rasul and Thapa, 2003). There are crops like sugarcane (Saccharum officinarum) that seem to be unsuitable for agroforestry (Pinto et al., 2005). Development of local capacities for consensus building constitute a critical step prior to collective action by farming communities resulting in the adoption of integrated soil fertility management strategies at the farm and landscape scale (Barrios et al., 2006). However, promoting and supporting participatory technologies have limited impact when no attention is paid to participatory policy development and implementation (de Jager, 2005; Desbiez et al., 2004).

The adoption of conservation agriculture is also possible in marginal lands, since suitable equipment is available (hand, animal-drawn, or tractor-drawn) for resource-poor farmers (Bolliger et al., 2006; Unger, 1990). Reducing soil erosion losses by limiting soil erosion would go a long way to attain food security, especially in the developing countries of the tropics and subtropics (den Biggelaar et al., 2003 a; b). However, efforts to promote conservation agriculture will have to be tailored to reflect the particular conditions of individual locales (Knowler and Bradshaw, 2007). Water harvesting structures requires the use of plastic sheeting as reservoir sealant, and it is only economically viable if combined with improved soil fertility management (Fox et al., 2005).

Municipal waste materials, whether in composted or uncomposted forms (such as leaves and grass clippings, sludges, etc.), can be valuable soil amendments for farms near cities or towns because of their expensive transport costs (Kashmanian et al., 2000; Smith, 1996), provided they possess the qualities needed by their potential users and do not possess toxics. Other developments are expected to result from biotechnology investigations, for instance, efficient N fixation by non legume crops (e.g., Azospyrilllum, etc.), P solubilizing bacteria, and mycorrhizal associations in tropical cropping systems and to increase mycorrhizal benefit (Cardoso and Kuyper, 2006).

6.4.1.2 Challenge: Enhance the resilience of soils to degradation resulting from climate change.

The projected intensification of the hydrologic cycle will significantly challenge AKST efforts to control soil erosion and rehabilitate degraded lands. Climate simulation models indicate substantial future increases in soil erosion, even in well-endowed production environments (Nearing, 2004; Williams et al., 2000). Tropical soils with low organic matter are expected to experience the greatest impact of erosion on crop productivity because of the poor resilience of these soils to erosive forces, and the high sensitivity of yields to cumulative soil loss (Nearing, 2004; Stocking, 2003). Evidence of significant soil erosion can often be difficult to detect, and its impact on crop productivity can be masked by use of inorganic fertilizer (Boardman, 2006; Knowler, 2004). Extreme events, which significantly contribute to total erosion, are very likely to gain even greater importance with climate change (Boardman, 2006), as well also climate-induced changes in land use that leave soils vulnerable to erosion (Rounsevell et al., 1999).

Option: Improve soil erosion modelling capacity. Current soil erosion models do not adequately capture the role of extreme events in soil erosion, nor do they adequately encompass the influence of socio-economic factors on land-use change (Boardmann, 2006; Michael et al., 2005). Further advances in integrating statistical downscaling of General Circulation Models into soil erosion models will be an important option for AKST. One such newly emerging technique is the use of meteorological time series projections to estimate the impact of more frequent extreme events under different climate scenarios (Michael et al., 2005). There are also a few relatively simple options for improving AKST capacity in extreme events erosion modeling. They include broader use of two-dimensional hillslope models (Broadman, 2006) and use of GIS to develop landslide hazard maps (Perotto-Baldiviezo et al., 2004). Prioritization of erosion ‘hotspots’ would also help to bring greater focus on the threats posed by climate change as well as soil erosion on steepland production zones. Boardman (2006) proposes broad assessments of these areas using field surveys, experimental plots, expert analysis, and sediment load measurements.

<u>Assessment</u>: Continued developments in modelling techniques that utilize downscaling from General Circulation Models show good potential for estimating the impact of extreme events under future climate, though they will likely continue to be limited by uncertainty in global climate models (Zhang, 2005). Also, the lack of quantitative data and the technological complexity of many contemporary models is likely to limit the applicability of soil erosion modeling in less developed steepland regions (Boardman, 2006; Morgan et al., 2002). AKST could address this issue through better field-level assessments of current erosion under

different crops and management practices. These efforts could help to more fully describe the scope of the problem, and inform planning of future cropping system options for soil protection under climate change. In addition to field surveys, wider use of remote sensing and GIS in remote locations could help in characterizing where land use change may increase the vulnerability to erosion, and this technology can provide locally accessible tools for integrating socioeconomic trends into soil erosion vulnerability assessments.

Option: Improve adoption of soil conserving practices. The adoption of practices and technologies that enhance vegetative soil coverage and reduce soil disturbance will become critical to future crop productivity under climate change. These include expanding the use cover crops, surface retention of crop residues, conservation tillage, green manures, agroforestry, and improved fallow (Benites and Ashburner, 2003; Lal, 2005; Sanchez, 2000).

<u>Assessment</u>: Although these are very sound practices for soil protection, achieving broad-scale and long-term adoption of them will be a significant challenge for AKST given the current, and likely future, disincentives to investment including lack of stable land tenure, growing importance of non-farm income sources, ready access to mineral fertilizer, and shortages of rural labor supply (Knowler, 2004; Stocking, 2003). These constraints need not preclude action, but they do point to the importance of developing policies that provide incentives for conservation agriculture within the larger context of sustainable development, such as with payment for ecosystem services. Institutional capacity will also need to be strengthened at the farm level, through improving linkages between applied research, extension, and farming communities, to develop locally relevant soil conservation strategies (Knowler, 2007).

A greater research effort will be needed to understand, and therefore optimize, the range of multiple services provided by soil conserving technologies. For example, in addition to biological N fixation and soil protection, green manure legumes influence pest dynamics, usually but not always in a beneficial manner, and provide some marketable products including animal fodder (Ali, 1999; Cherr et al., 2006). These benefits have not been systematically documented. Future research efforts would benefit from being whole-systems and multi-contextual in nature, and involve collaborations by plant breeders, pest and soil management, and livestock experts linked to farmer-participatory research.

Changes in rainfall patterns, and increased rainfall variability, under climate change could undercut the ability of AKST to promote the adoption and maintenance of soil conservation practices. Greater focus on underutilized forage and crop legumes would help to broaden the scope of future AKST options. One such example is grasspea (Lathyrus sativus), which is drought, salinity, and submergence tolerant but needs greater research efforts to develop varieties that have low neurotoxin levels (Patto et al., 2006). The resilience of conservation farming systems in the Central American highlands to recent El Niño drought (Cherrett, 1999), and to the catastrophic soil losses from Hurricane Mitch (Holt-Gimenez, 2001) provide strong evidence of conservation agriculture's potential as an adaptation response to increased seasonal variability and storm intensity with climate change.

6.4.2 Water resources

6.4.2.1 Challenge: Improving management of water resources and irrigation

Option: Design, develop and manage water resources infrastructure from a multiple use livelihoods perspective to maximize benefits per unit of water, and improve health. Integration of various water use sectors including crop, livestock, and fisheries in infrastructure planning can result in increased overall productivity at the same level of water use, and can be compatible with improving health. (Hussain, Castillo et al., 2007)

Assessment:

Crops to be added

Livestock to be added

Fisheries can be enhanced in many water management structures such as small dams, reservoirs, and impounded floodplains through stocking with appropriate fish species, greatly increasing productivity of the water management structures. Stocking technologies have given very high rates of yield in lakes as reviewed by Welcomme and Barley (1998); in dams and reservoirs in Thailand, Indonesia, the Philippines and Malaysia (Fernando, 1977), in China (De Silva, 2003), and India (Sugunan and Katiha, 2004); and in floodplains in Hungary (Pinter, 1983), Bangladesh (Ahmed, 1998), and India (Sugunan and Sinha, 2001). Species introductions, and other enhancement technologies, such as fish holes, drain-in ponds, dugouts and finger ponds are also effective in increasing production (CA fisheries chapter). Improved stocking management can also increase production in integrated agriculture-aquaculture (IAA) systems. A widespread type of IAA is integration of fish into rice paddies. While typically rice paddies produce 120-300 kg/ha/yr of mixed fish which contribute directly to household diets, managed fish stocking and harvest can increase rice yields (due to weed control and the aeration of soils) by some 10% while producing up to 1,500 kg/ha of fish (dela Cruz, 1994; Halwart and Gupta, 2004).

Water management strategies such as alternate wet and dry irrigation, water saving irrigation technologies, and modernization of infrastructure to minimize standing water reduce sites for vector breeding, and institutional reforms such as creation of Water Users Associations (WUA's) or improvement in extension services, can bridge the gap between agricultural and health departments (Bakker et al., 1999). Banning the use of the most toxic pesticides and promoting IPM is a high priority for preventing poisoning, (Eddleston et al., 2002). In general, human health interests and environmental interest are complimentary. Operation of existing dams can be re-optimized to improve health and environmental performance, such as to restore floodplain ecosystems, and new irrigation schemes can be planned and designed to minimize environmental impacts (Faures, et al. 2006).

Option: Implement management strategies that improve equity in irrigation systems. It has been shown that equity and productivity enhancement can often be complimentary in irrigation systems (Hussain, 2005).

Assessment Land distribution that results in larger numbers of smaller holding improves benefit sharing. Appropriate irrigation service charges can ensure adequate spending on operations and maintenance; poor people tend to suffer the most when system level maintenance is inadequate. Displacement impacts can be mitigated through appropriate processes (Hussain, 2005). More to be added

6.4.2.2 Challenge: Adapting to water scarcity

There is broad agreement that future increases in water scarcity will turn water into a key, or the key, limiting factor in food production and livelihoods generation for poor people virtually throughout rural Asia and most of Africa, with particularly severe scarcity in the bread baskets of North-West India and Northern China (Molden et al., 2007). Aquatic ecosystems, and people who depend on them for their livelihoods, are likely to be the biggest losers as more and more fresh water is diverted to agriculture.

Option: Increase water productivity by increasing returns per unit of evapotranspiration. In many parts of the world reducing evaporation and removing soil constraints, are still important options for increasing water productivity.

Assessment: There is significant scope to reducing ET per unit of yield by reducing evaporation and improving soil quality, as recently assessed by Molden et al., 2007. Evaporation in irrigated systems varies between 4% to 25% depending on water application methods (Burt et al., 2001), and from 30-40% and more in rainfed systems (Rockstrom et al., 2003). The amount of evaporation depends on climate and how much of the soil is shaded by leaves (the crop canopy), and can be very high in rainfed systems with low plant densities. Practices increasing water productivity such as mulching, plowing, or breeding for early vigor of leaf expansion in order to shade the ground as rapidly as possible or longer superficial roots can reduce evaporation and increasing productive transpiration.

Besides crop and fields practices, there is significant scope for reducing evaporation at the basin and landscape scales. High evaporation rates from high water tables and waterlogged areas can be reduced by drainage, or reducing water applications, after first taking care that these are not wetland areas supporting other ecosystem services. In degraded arid environments, up to 90% of rainfall evaporates back into the atmosphere with only 10% made available for transpiration. Water harvesting in dry areas is an effective method of making available the non-beneficial evaporation of rainwater for crop transpiration (Oweis, 1999). Micro and macro-catchment techniques capture runoff and make it available for plants and livestock before evaporation, increasing beneficial rainwater available for T, nearly halving E and quadrupling the increase in T. Improvement of soil fertility can significantly improve transpiration efficiency, and improving soil physical properties including infiltration and water storage capacity can reduce evaporation, together resulting in 100% or larger increases in crop water productivity (Bossio et al., 2007). Molden et al. (2007) further conclude that only moderate impacts on crop water productivity should be expected from plant genetic improvements over the next 15 to 20 years. These gains will primarily be through breeding strategies that target crops like millet and sorghum that have not received as much attention as the green revolution grains. An opportunity for improving value per unit of water also lies in enhancing nutritional quality of staple foods. Here perhaps rDNA biotechnology may offer significant potential over time (Molden et al., 2007).

Crop plants adapted to higher water stress by breeding or rDNA may also be more effective weeds in these and other environments (see 6.1.1.2). Through rDNA, the adapting genes are likely to be linked, leading to even faster evolution of weeds through gene flow.

Option: Maintaining returns with reduced water delivery to irrigation systems.

Assessment: There are significant opportunities in irrigation to improve irrigation water productivity through a combination of field and system management practices, and policy incentives, that raise water productivity, manage salinity an increase yields (e.g., Van Dam et al., 2006). In addition to producing more food, there are ample opportunities in irrigation to generate more value, and incur less social and environmental costs. Supplemental irrigation, the addition of small amounts of water at the right time to supplement rain is probably the best way to increase water productivity of supplies. This can be further increased with deficit irrigation, where water supplied is less than crop requirements (Zhang, 2003). In Western Syria, yields increased from 2 to 5 tons per hectare with the timely application of 100 to 200 mm of water (Oweis et al., 2003). In Burkina Faso and Kenya, yields of 0.5 tons per hectare were increased to 1.5 to 2.0 tons per hectare with supplemental irrigation combined with soil fertility management (Rockstrom et al., 2003). There is substantial scope to reduce water deliveries to irrigation, especially to rice (Bouman et al., 2007).

Add assessment of financial costs

Reducing supplies does not necessarily save water; and can have unintended detrimental side effects that can be understood by considering what happens to drainage flows. A common (mis)perception is that because irrigation is typically 40 to 50% efficient at converting irrigation water into ET, there is enormous amounts of water that could be saved if drainage flows could be reduced (see Seckler 2003 et al. for a discussion). But because so much drainage flow is reused downstream, there is actually much less scope in saving water in irrigation than commonly perceived. In fact, in irrigated regions in dry areas it is common to document ratios of ET to irrigation plus rain greater than 60% reaching to over 100% when aquifers are mined. These areas include the Gediz basin in Turkey (Droogers and Kite, 1999); Egypt’s Nile (Keller and Keller, 1995); Chistian sub-division in Pakistan and the Bhakra irrigation system (Molden et al., 2000); the Liu Yuan Ku irrigation system (Khan et al., 2006); the Tunuyuan irrigated area in Argentina; the Fayoum in Egypt; and Nilo Coelho in Brazil (Bos, 2004). Renault et al. (2001) show that the perennial vegetation at Kirindi Oya evapotranspire about the same amount of water as rice, generate valuable ecosystem services giving a different picture (65% of inflows beneficially depleted) than if paddy rice were considered alone (22% of inflows depleted by rice). In these cases, the problem is not wastage, but that high withdrawals and ET rate reduce drainage and tend to dry up rivers and wetlands, and leave little to downstream use. It is important to consider each case taking a basin perspective considering the quality and quantity of water and how drainage flows are used downstream.

6.4.3 Biodiversity and ecosystem services

6.4.3.1 Challenge: Reducing loss of biodiversity

Option: preventing further loss of existing important habitats

Assessment: Losing habitats is the greatest threat to biodiversity. According to the Millennium Ecosystem Assessment, over the past 50 years people have changed or eroded ecosystems faster and more extensively than in any period in human history. Rapidly growing demands for food, freshwater, timber, and fuel drive this change. Humans commandeer an enormous amount of the planet's productivity – experts estimate we use up to 40% of all plant growth on land, and 25-30% of marine production, putting enormous pressure on biodiversity. So what can AKST do to prevent further loss?

Option: Habitat restoration.

Assessment: Habitat restoration is a way of improving degraded ecosystems or creating new areas to compensate for loss of habitat elsewhere. So which types of habitats should be restored? How can AKST help?

Option: Control of entry invasive species.

Assessment: Invasive species move into new habitats by a variety of means. For example, exotic plants are transported by seed moved by migrating birds and international trade. The key factor for predicting a successful invasion seems not to be particular phenotypic characteristics of the invader, but the scale and frequency of introductions (Lavergne and Molofsky, 2007; Novak, 2007). Since scale of introduction is a critical factor, commercial trade in seeds and other kinds of plant propagules, or livestock, has the greatest potential to augment the invasion potential of exotic species. The most promising mechanism for targeting this critical phase in invasion is an increase in the capacity of exporting and importing nations to monitor the content of agricultural goods. No single country can effect this level of monitoring effectively, so more emphasis on the global capacity building activities surrounding the Cartagena Protocol on Biosafety, TRIPs and the Sanitary and Phytosanitary Agreement (SPS) is essential. Replace with trext on controlling invasions

6.4.3.2 Challenge: Reducing land degradation and loss of agricultural land

Option: Prevent deforestation. Existing data suggest that the tropics, where deforestation and forest degradation have been more extensive, are more threatened by deforestation. In all regions of the humid tropics –Latin America, Southeast Asia, and Central Africa- deforestation is primarily the result of a combination of commercial wood extraction, permanent cultivation, livestock development, and the extension of overland transport infrastructure (Nelson, 2005; Vosti et al., 2003; Zhang et al., 2002).

Option: Promote alternatives to contribute to forest conservation, such as off-farm employment generating sufficient manufacturing/service jobs for ex-farmers (Grainger et al. 2003, Mulley and Unruh 2004), or choosing a high-tech industrial development model, based on the production of high-added value products combined with air transport (Fenley et al. 2007).

Option: Promote alternatives improving management of forests, such as promoting multiple-use policy in natural forests and the plantation of economic (cash) tress within forests (Pearson et al. 2002, Wenhua et al. 2004).

Assessment: Local authorities are inefficient in monitoring and enforcing environmental laws in large regions, like the Brazilian Amazonia (Fenley et al. 2007). In this region the construction of highways combined with promotion of agriculture and cattle ranching facilitated deforestation spreading (Fenley et al. 2007). Off-farm employment arises as an alternative to contribute significantly to forest conservation in the tropics, as shown by a case of tea industry in western Uganda (Mulley and Unruh, 2004). An example of forest management was implemented by the Chinese government, which articulated the new forest policy from 1998. Its purposes are to: i) restore natural forests in ecologically sensitive areas; (ii) plant forests for soil and water protection; (iii) increase timber production in forest plantations; (iv) protect existing natural forests from excessive cutting; (v) maintain a multiple-use policy in natural forests. The strategies for sustainable forestry development are to improve the policy system and legal system, improve capacity and set up technological safeguard systems, and establish a forestry economic system in conformity with the requirements of a market economy (Wenhua et al. 2004). Farmed parkland evolves from natural woodland in stages which may be observed in any dynamic field situation in West Africa, including the Sahel, where the selection, protection and systematic harvesting of the products of 'farm trees' and shrubs are universal practices (Mortimore and Turner 2005). Sustainable timber management implies taking steps to ensure forests continue to produce timber in the longer-term, while maintaining the full complement of environmental services and non-timber products of the forest. However, although sustainable timber management sometimes provides reasonable rates of return, conventional timber . harvesting is generally more profitable. This implies that without additional incentives, one cannot expect companies to adopt sustainable management (Pearce et al. 2002).

<u>Option:</u> Preventing dryland degradation by erosion and salinization.
Water and wind erosion was reported as the prime cause for 87% of the degraded land (Nelson, 2005).

<u>Option:</u> controlling sediment loss by: a) planting windbreaks and special crops to alter wind flow; b) retaining plant residue after harvesting; c) tilling soil to bury erodible particles, d) create aggregates that resist entrainment, d) increase surface roughness;e) improving farm equipment; and f) stabilizing soil surfaces using water or commercial products (Nordstrom and Hotta 2004).

<u>Option:</u> Recognized options for management of salinity risk, or to reduce existing areas of saline soil, are revegetation of part of the cleared land with alternative species, pumping to lower the water table in selected areas, and construction of ditch drains for control of surface water and shallow groundwater (Peck and Hatton 2003). In irrigated areas it is essential to improve water use efficiency, which is often as low as only 40 % (Deng et al. 2006).

Assessment: Improved management practices to prevent sediment loss may be effective where accepted by farmers (Nordstrom and Hotta 2004). Many management techniques do not require sophisticated technology or great costs to implement, but they may require a willingness of farmers to change practices. Barriers to adoption of conservation measures include start up or transition costs associated with new methods or equipment, inadequate education, reliance on past traditions, or a history of failed field experiments (Bunn1997, Uri, 1999). Reluctance to implement soil-conservation policies and practices can be overcome when severe erosion events associated with periods of drought remind farmers and the rest of society of the advantages of compatible methods of farming (Bunn 1998, Todhunter and Cihacek, 1999).
Available data on the extent of land degradation are extremely limited, and paradigms of desertification are changing (Herrman and Hutchinson, 2005). Approximately 10% of the drylands are considered degraded, with the majority of these areas in Asia. All options for management of salinity risk are constrained by the economics of dryland farming, and pumping or drainage is further constrained by possible environmental impacts of disposal of saline water. In Australia, by far the bulk of effort has been directed at ”living with saline land and water”, with immense public and private investment in tree planting and the search for new low recharge farming systems (Peck and Hatton 2003). Practices to improve water use efficiency include biological mechanisms of water-saving agriculture and water-saving irrigation technologies, including low pressure irrigation, furrow irrigation, plastic mulches, drip irrigation under plastic, rainfall harvesting and terracing (Deng et al. 2006).

Option: Preventing agricultural expansion and abandonment.
Most technical options are similar to those for preventing deforestation. They are also based on the promotion of off-farm employment (Grainger et al. 2003, Mulley and Unruh 2004), or the production of high-added value products combined with air transport (Fenley et al. 2007).

Assessment: Three major pathways were identified toward agricultural intensification: land scarcity in economies weakly integrated into world markets, market integration, and region specific interventions, in the form of state-donor, or NGO – sponsored projects (Nelson, 2005). Cultivation of new lands in some biomes would neither compensate nor justify the loss of irreplaceable ecological services. Other biomes have smaller sensitivity, and would not be equally affected. The functional complementation of biomes seems to be a smart strategy to explore on land use options on broad scale basis (Viglizzo and Frank, 2006). This is the case of agricultural expansion in South America (e.g., Argentina, Bolivia, Brazil, Colombia), based on the replacement of natural forests by cattle ranching and soybean cropping (Cardille and Foley, 2003; Etter et al., 2006; Pacheco, 2006; Vosti et al., 2003). Shifting cultivation in Africa also led to deforestation and degradation (Zhang et al., 2002). There are potential benefits to conservation management that arise from agricultural land abandonment or extensification. In China conversion of cultivated land has not hurt national food security, since many converted lands had low productivity (Deng et al., 2006). However, agricultural land abandonment increases the vulnerability of farmers. This shows that positive outcomes in one sector could have adverse effects elsewhere (Rounsevell et al., 2006). However, according to Wood and Lenné (2005) much of the ecological criticism of agriculture in developing countries is unfounded and the concept that agriculture threatens biodiversity based on the Convention on Biological Diversity (CBD) might be rejected.

Mixture of options, assessment and historical /current – redraft, deleting inappropriate text

A major portion of the C-sink in the northern mid-latitudes (although probably not in the tropics) is a result of recovery from past changes in land use and management. That is the case of afforestation or sustainable forest management and preservation (Houghton, 2002). Modern biomass energy will gain share in the future energy market, and abandoned agricultural land is expected to be the largest contributor for energy crops. For the year 2050 the geographical potential of abandoned land ranges from about 130 to 410 EJ yr^{-1}. For the year 2100 it ranges from 240 to 850 EJ yr^{-1}. At a regional level, significant potentials are found in the former USSR, East Asia and South America (Hoogwijk et al., 2005).

6.4.3.3 Challenge: use AKST to prevent or mitigate consequences of conflict over environmental resources.

Efforts to preserve natural resources and guarantee the provisioning of essential ecosystem services are frequently characterized by social, political and legal conflicts (Wittmer et al., 2006). Broad-scale approaches are necessary to face problems that extend beyond a local site and a short time span, and perceive critical bio-physical and socio-economic variations and asymmetries in time and space.

The asymmetric administration of shared lands and natural resources, for example, is a potential source of conflict in many trans-boundary eco-regions of the world (Viglizzo, 2001). The cross-border externalization of negative environmental impacts due to asymmetries in land conversion and intensity farming rates represent an increasing challenge to be faced by many neighbour countries. The problem may become critical in shared basins where interconnected rivers and streams are the way to quickly externalize negative impacts. Not strangely, downstream countries have to pay the cost damages that have not been properly internalized by the upstream ones.

> An illustrative example is the environmental threat due to a waterway construction project in the Pantanal eco-region in South America (Bucher and Huszar (1995). Pantanal is one the world's largest wetlands with an estimated area of 140 000 km2 that is shared by Brazil, Bolivia and Paraguay. The study showed that the functional alteration of the wetland to boost the agricultural business would provoke uncontrolled rises and lows in river levels, causing catastrophic floods over downstream lands, increase of pollution and coastal erosion, irreversible destruction of habitats for biodiversity, and expansion of vector-borne diseases.

Option: Participatory approaches supported by knowledge and technology aim at enhancing the commitment of stakeholders in the decision-making process and to share the responsibility of managing common resources. Agricultural and environmental conflicts are characterized by the interaction of both ecological and societal complexity (Funtowicz and Ravetz, 1994). Participatory approaches (De Marchi et al., 2000) and multi-criteria analysis (Paruccini, 1994) emerge today as new strategies for resolving agro-environmental conflicts. The multi-criteria analysis (MCA) deals with the potential of different approaches (normative, substantive and instrumental) to face different types and levels of conflict resolution. They offer the information base necessary to undertake common trans-boundary conflicts. MCA, or multi-objective decision making, is a powerful analytical tool applicable to cases where a single decision-making criterion fails. For example, in cases where social, ecological or environmental impacts cannot be assigned monetary values. Different social, ecological and environmental indicators, developed side by side with the economic ones, can be fruitfully applied to multifunctional agricultural landscapes where the trade-offs between multiple attributes have to be assessed to design policies or make decisions. Both instruments, PA and MCA, must be supported by knowledge and technology. They offer the information base necessary to undertake common trans-boundary conflicts.

Most agricultural technology aims at resolving environmental problems that occur at the small spatial scale (e.g., the plot and farm level). But broad-scale technologies (Stoorvogel and Antle, 2001) are necessary to reveal impacts that are not perceived on site-specific studies. The importance of information technology increases as we scale-up to undertake problems that occur at broader geographical scales. The integration of maps, remote-sensing images, and data bases into geographic information systems (GIS) is demanded to assess, monitor and account critical resources and large-scale agro-environmental processes (See also sub-chapter 7.4). This information base, coupled to models and expert systems (De Koning et al., 1999), can helpfully support the application of participatory approaches and multi-criteria analysis to resolve present or potential conflicts. Likewise, these tools give place to decision-support system to agree on large-scale land-use policies and managerial schemes.

Assessment: Decision- and policy-making options to improve the management of conflicting areas like shared basins must (a) introduce and accept the notion of basin unit, which is grounded on the assumption that trans-boundary basins must be managed as a whole functional ecological unit by neighbor areas and countries, (b) avoid the generation of negative externalities from up-stream areas to areas located on down-stream lands in the basin, (c) agree on jointly designed land-use strategies to prevent potential conflicts due to negative externalities from neighbor areas or countries, (d) undertake the environmental impact assessment as a normal practice to get ex-ante evaluation of potentially conflicting projects, (e) agree on the acceptance of third-party independent arbitration to face current or potential conflicts when necessary.

6.4.4 Persistent chemicals

6.4.4.1 Challenge: Tackling persistent chemicals in the environment to protect human health and the environment

Option: development of more effective management strategies for persistent chemicals. Many present and emerging threats can be mitigated by currently available technologies, like precision agriculture (see subchapter 6.3.1). Bioremediation is still a developing science and basic research is still needed to better understand the factors affecting biotransformation processes (Adriano et al., 1999; Khan, 2005). Another new trend in bioremediation is the use of phytoremediation –plant based remediation- as cleanup tool.

Assessment: Promising techniques in this area offer hope to simultaneously treat organic pollutants through degradative (enzymatic) pathways via root-microbial associations, and both inorganic and organic waste by ground extraction of contaminants via root uptake to shoot biomass. Since phytoremediation is limited to the rooting zone, it will find its widest application in the remediation of surface-polluted soils. Further analysis and discovery of genes for phytoremediation will benefit from the recent development of segregating populations for a genetic analysis of naturally selected metal hyperaccumulation in plants, and from comprehensive ionomics data – multi-element concentration profiles from a large number of Arabidopsis mutants (Krämer, 2005).

The idea of intrinsic remediation, i.e. the use of indigenous organisms, has been nurtured during the last several years as an alternative to introducing genetically engineered organisms to affected sites. Indigenous organisms have been shown to degrade industrial solvents (e.g. PCBs) and many pesticides (Sadowski and Turco, 1999). In situ bioremediation cleans the soil without excavation, and despite being time-demanding; its cost is lower than on site bioremediation techniques. We should never predict complete removal of the contaminants, but only of the mobile and easily available fraction (Doelman and Breedveld, 1999). Phytoremediation has potential risks, such as those associated to the use of transgenic techniques, release of nonindigenous (potential weed) species and transfer of toxic compounds to the other environmental compartments (Alkorta and Garbisu, 2001; Wenzel et al., 1999).

Option: development of more effective technologies for identifying early impacts of pollution on ecosystems.

Assessment: Preventing or limiting the flow of chemical pollutants into the environment should be more effective at limiting damage than remediation. Damage caused by pollutants could be prevented if the source of the pollution and the presence of the pollutants could be identified at minimal concentrations. New technologies that significantly increase awareness of biological impacts are being discussed in the research literature. These include biosensors and chemical approaches (Heinemann et al., 2006; Water Science and Technology Board., 2001). These approaches can also use indigenous organisms.

6.5 Options to Adapt to Climate Variability and Change, and Mitigate Agricultural Greenhouse Gas Emissions

6.5.1 Adaptation to climate change

The effectiveness of AKST's adaptation efforts is likely to vary significantly between and within regions, depending on geographic location, vulnerability to current climate extremes, level of economic diversification and wealth, and institutional capacity (Burton and Lim, 2005). Industrialized-world agriculture, generally situated at high latitudes and possessing economies of scale, good access to information, technology and insurance programs, as well as favorable terms of global trade, is positioned relatively well to adapt to climate change. By contrast, smallholder rainfed production systems in semi-arid and subhumid zones presently contend with substantial risk from seasonal and interannual climate variability. Agricultural communities in these regions generally have poor adaptive capacity to climate change due to the marginal nature of the production environment and the constraining effects of poverty and land degradation (Parry et al., 1999). (Note: A table of adaptation options is on page 62.)

6.5.1.1 Challenge: Enhance the performance of current AKST for addressing seasonal and interannual climate variability

The knowledge and tools currently at AKST's disposal could be better deployed to reduce the vulnerability of rainfed agriculture to seasonal climate variability. For example, poor crop establishment is a significant but solvable constraint in semi-arid farming environments (Harris, 2006). Similarly, seasonal dry spells can be bridged using improved rainfall catchment and incremental amounts of fertilizer (Rockström, 2004). By focusing on the "manageable part of climatic variability" (Rockström, 2004), AKST could make a significant positive impact on improving the adaptive capacity of rainfed agriculture to climate change.

Option: Target technologies and practices that reduce the exposure of sensitive crop growth stages to seasonal climate variability. The greatest period of risk in rainfed agriculture is the uncertainty around the timing of sufficient rainfall for crop sowing. High rainfall variability and poor quality seed leads to slow germination and emergence, causing patchy stands, and multiple and delayed replanting, making poor crop establishment a significant contributor to the productivity gap in semi-arid agriculture (Harris, 2006). Options for addressing this

challenge include improving farmer access to quality seed, adoption of improved crop establishment practices, and the use of healthy seedlings in transplant systems.
Seed priming— the practice of soaking seeds in water for several hours but short of that which could trigger pregermination — is an example of a simple but effective technology for improving crop establishment. Priming of seed results in more even and full stand establishment, and it accelerates seedling emergence and improves early growth, often leading to earlier flowering and maturity, avoidance of late-season drought and improved yields (Harris et al., 2005; Harris, 2006). Experimental crop transplanting methods in millet-sorghum areas of Africa can also reduce planting risk, through transplanting from small seedling nurseries, staggered 10 days apart to allow for variable onset of the rainy season (CAZS, 2006; Mottram, 2003; Young and Mottram, 2001). This method, though more labor intensive, results in faster crop establishment with fewer gaps, and harvest 2-3 weeks earlier than conventional seeding methods, leading to higher grain and stover yields. Solarization of nursery seedbed soil (see section 6.x.x) is another low-cost means of improving root seedling health, and thus yield performance in lowland rainfed rice, where ephemeral drought and high root pest pressure limit crop productivity.

Assessment: By reducing crop establishment risk and decreasing the time to maturity, these technologies provide a small measure of flexibility to farmers in high-risk environments. Technologically simple approaches to improve crop establishment and seedling vigor generally have minimal downside risks, immediate and tangible benefits, and can be easily tailored to producer needs; thus, they are appropriate options for smallholder rainfed systems. Seed priming, which has been tested in a wide array of dryland cereals and pulses, consistently lead to an average of 30 percent increase in yield with minimal farmer investment (Harris, 2006). Similar mean yield increases have been observed with seedbed solarization of rice nurseries, though with somewhat greater farmer investment in material and time. While these are simple technologies, they do require some local testing and training to ensure that proper techniques are followed, for instance that seed priming does not lead to pregermination. Millet transplanting systems show good potential, though labor shortages could be an issue in some regions. An analysis of the tradeoff between labor for transplanting versus the labor and extra seed required for multiple resowing of millet fields would help to clarify the issue of labor expenditure.

6.5.1.2 Challenge: Reduce the negative feedback between chronic drought risk and low soil productivity in rainfed environments.

The high risk of crop failure from insufficient soil moisture hinders investments in soil fertility and tilth, which in turn diminishes the potential of soils to capture and retain water, therefore increasing the vulnerability to drought. A challenge for AKST will therefore be how to couple incremental improvements in crop water relations with low-cost investments to replenish soil fertility in order to break this cycle (Rockström, 2004; Sanchez, 2005).

Option: Improve seedling nutrition. A viable option for small-holder production systems would be to refine and more widely disseminate the practice of adding small quantities of fertilizer to seed, such as through seed coating (Rebafka et al., 1993) or soaking/priming (Harris, 2006) methods. Addition of fertilizer P and micronutrients to seed, rather than soil, is an inexpensive but highly effective means for improving plant nutrition and increasing yield (> 30 percent average yield increase reported) on drought-prone, acidic, low fertility status soils. Seed priming with dilute fertilizer has average benefit/cost ratios 20 to 40 times greater than that achieved with fertilizer addition directly to soil (Harris, 2006).

Assessment: This is could be an effective strategy for smallholder systems, though there are several impediments such as low availability of quality fertilizer in local markets, lack of extension services for conveying technical information, and inability of farmer to pay for fertilizer-treated seed. Imbedding these technologies within larger efforts to overhaul the seed sector, which could include credit for purchasing improved seed and information about improved crop establishment practices, as detailed above in Challenge 1, Option A, could facilitate farmer adoption of these technologies. Also, these technologies could be disseminated into local communities by targeting farmers that have made prior land improvements to increase soil water retention (see Option B below), and may therefore be less risk adverse.

Option: Rehabilitate abandoned degraded land. Long-term investment in rehabilitating degraded lands is another option for addressing the negative feedback between high rainfall risk and declining soil fertility. Recent evidence of revegetation and agricultural intensification in the Sahel, catalyzed by a crisis of diminished rainfall and declining yields (Herrmann et al., 2005; Reij et al., 2005; Tappan and McGahuey, 2006; USAID, 2006), could inform future

AKST efforts at integrating soil and water conservation and land reclamation into adaptation planning. Technologies and practices that were deployed in these areas to reclaim declining or abandoned land include rock lines, rock 'Vs', and manure-amended planting pits that were used to break soil crusts and enhance water capture and retention, and farmer-managed natural regeneration of N-fixing trees to improve soil fertility. The soil reclamation phenomena described here was wide spread, encompassing several hundred thousand hectares in Burkina Faso and Mali, and well over a million hectares in Niger (Reij et al., 2005; Tappan and McGahuey, 2006; USAID, 2006).

Important elements gleaned from these studies include:
Legal code reforms that provided farmer, rather than government, ownership of trees was an essential precondition;
The process was driven by both autonomous action and development assistance, with the former sometimes taking the lead and the latter following;
By improving land and claiming ownership, women were one of the main beneficiaries, and improved household food security one of the most tangible outcomes;
Investment in fertilizer occurred after farmers invested in measures to conserve soil moisture and increase soil organic matter.

Assessment: AKST could play an important role in documenting the effectiveness of these practices for seasonal climate risk management, for instance through investigating how these soil improvement practices impact soil fertility, soil moisture retention, and crop yields over a range of variable rainfall years, as well as conducting detailed socioeconomic analyses of how the benefits are distributed in local communities. Local control of the resource base is necessary for creating the enabling conditions that spur local action towards natural resource improvements, and AKST will need to understand this dynamic in order to effectively support local initiatives. Stabilizing and improving the natural resource base of agriculture are essential preconditions for investing in technologies for long-term adaptation to climate change (Sanchez, 2005; Stocking, 2003), such as through the deployment of improved varieties and expansion of irrigation. Thus, the lessons that are emerging from the Sahel should be carefully considered by AKST in order to assess their broader applicability for adaptation.

6.5.1.3 Challenge: Improve access to water and efficiency of water use

Option: Improve access to water. Target the poor with small scale, divisible, affordable water management technologies combined with enabling financing options.

Assessment: Technologies such as treadle pumps, small diesel pumps, low-cost drip, and low-cost water storage can increase productivity and incomes for poor farmers (Sauder 1992; Shah et. al. 2000; Lipton 2001; Kay et. al. 2000; SOMRA-MBL 2003; Keller et. al. 2001; Polak et. al. 2004). These approaches provide water at lower unit costs than large scale hydraulic infrastructure, and can be available immediately, without the long delay times of larger scale projects. Innovative development and marketing approaches which focus on increasing local private enterprise capacities and market promotion have been credited with successful dissemination to the poor (Shah, et al., 2000).

Option: Improve efficiency of water use in agriculture. Reduce water related risk through adaptation and adoption of strategies to improve water productivity in rainfed farming systems. These strategies entail shifting from passive to active water management in rainfed farming systems and include water harvesting systems for supplemental irrigation, small scale off-season irrigation combined with improved cropping system management, which comprises various aspects, such as the use of water harvesting tillage systems (conservation tillage), improved crop varieties, improved cropping patterns (Molden et al., 2007), and particularly mitigation of soil degradation (Bossio et al., 2007). These technologies allow active management of rainfall (green water), rather than management only of river flows (blue water) (Rockstrom et al., 2006).

Assessment: The scope for improvement is tremendous in scale (Molden et al. 2007). Rainfed farming covers most of the worlds croplands (80%), and produces most of the worlds food (60-70%). Poverty is particularly concentrated in tropical developing countries in rural areas where rainfed farming is practiced (Castillo et al., 2006). Half of the currently malnourished are concentrated in the arid, semi-arid and dry sub-humid areas where agriculture is very risky due to extreme variability of rainfall, long dry seasons, and recurrent droughts, floods and dry spells (Rockstrom, et al., 2006). Current productivity is generally very low (yields generally less than ½ of irrigated systems and in temperate regions where water risks are much lower). Even in these regions, there is generally enough water to double or often quadruple yields in rainfed farming systems. The challenge is to reduce water related risks rather than coping with absolute scarcity of water. With small investments large relative improvements in agricultural and water productivity can be achieved in rainfed agriculture. Small investments providing 1000 m^3/ha (100 mm/ha) of extra water for supplemental irrigation can unlock the potential and more than double water and agricultural productivity in small-scale rainfed agriculture, which is a very small investment compared to the 10000-15000 m^3/ha (1000 – 1500 mm/ha) storage infrastructure required to enable full surface irrigation (Rockstrom et al., 2006).

Option: Implement diverse water storage options planned at the basin scale. Climate change will require a new look at water storage, either to mitigate the impact of more extreme weather, cope with changes in total amounts of precipitation, and cope with changing distribution of precipitation, including shifts in ratios between snowfall and rainfall. Developing more storage (reservoirs and groundwater storage) and hydraulic infrastructure provides people with more influence in determining the precise allocation to desired activities including agriculture and hydropower production. In the process of adapting to climate change multiple interests at the basin scale can be incorporated and managed, and trade-offs with other livelihood and environmental interests must be included in the planning.

Assessment: to be added, Lead Author unable to complete in time to include in this round of review

6.5.1.4 Challenge: Improve seasonal climate forecasting skill and user access to seasonal climate information

Timely forecasts, including the starting date of the rainy season, average weather conditions over the coming season, and conditions within the season that are critical to staple crops and animals, along with appropriate responses can increase the economic, environmental, and social stability of agricultural systems and associated communities. Advances in atmospheric and ocean sciences, a better understanding of global climate, and investments in monitoring of the tropical oceans have increased forecasting skill at seasonal to interannual timescales. Early warning systems using seasonal forecasts (such as the FAO Global Information and Early Warning System) and monitoring of local commodity markets, are increasingly used to predict likely food shortfalls with enough advance warning for effective responses by marketing systems and downstream users.

Assessment: Bringing climate prediction to bear on the needs of agriculture requires increasing observational networks in the most vulnerable regions, further improvements in forecast accuracy, integrating seasonal prediction with information at shorter and longer time scales, embedding crop models within climate models, enhanced use of remote sensing, quantitative evidence of the utility of forecasts for agricultural risk management, enhanced stakeholder participation, and commodity trade and storage applications (Doblas-Reyes et al., 2006; Giles 2005; Hansen, 2005; Hansen et al., 2006; Sivakumar 2006). For seasonal climate forecasts to be an effective adaptation tool, advances in forecasting skill need to be matched with better pathways for dissemination and application, such as by linking forecasts to broader livelihood and development priorities, and by training trusted organizations, such as extension agencies, to facilitate the end users' ability to make effective decisions in response to forecasts (Garbrecht et al. 2005; Hansen 2005; Ziervogel 2004; Vogel and O'Brien, 2006). Substantial investments by national and international agricultural and meteorological services are needed.

6.5.1.5 Challenge: Reduce the potential for resource conflicts resulting from increased climate variability and climate change.

The impact of climate change may exacerbate risks of conflict over resources and further increase inequity, particularly in developing countries where significant resource constraints already exist. An estimated 25 million people per year already flee from weather-related disasters and global warming is projected to increase this number to some 200 million before 2050 (Myers 2002), with semi-arid ecosystems expected to be the most vulnerable to impacts from climate change refugees (Myers 2002; Surhke 1996). This situation creates a very serious potential for future conflict, and possible violent clashes over habitable land and natural resources such as freshwater (Brauch, 2002), which would seriously impede AKST efforts to address food security and poverty reduction.

Option: Improve conflict early warning networks. Traditional coping mechanisms depend on the ability to anticipate hazard patterns, which are increasingly erratic with the advent of climate change. One option for improving early detection and warning would be to broaden the use of novel GIS-based methodologies such as those employed by the Conflict Early Warning and Response Network (CEWARN), the Global Public Health Information Network (G-PHIN).

Assessment: Early warning systems are important because they help to untangle the multiple but interdependent crises that characterize complex emergencies, particularly in response to climate change. In other words, continuous information gathering serves to identify the socio-ecological ingredients of complex crises before they escalate into widespread violence. This means technological systems are also needed. To this end, the added value of technological early warning systems should therefore be judged on their empowerment of local people-centred systems that build on the capacity of disaster-affected communities to ‘bounce back’ or to recover with little external assistance following a disaster. Further applied research is needed on local human adaptability in decentralized settings as well as self-adaptation in dynamic disaster environments.

Linking early warning to more effective response requires a people-centred approach to climate change (UN 2006). The quest for early warning must be more than just an “exercise in understanding how what is happening over there comes be known by us over here” (Adelman 1998: 2). Instead, the international community should focus on the real stakeholders and add to their capacity for social resilience. On the policy front, the lack of institutionalized early warning systems that survey the localized impact of climate change on ecological and political crises inhibits the formulation of evidence-based interventions (Levy and Meier, 2004). Regrettably, little collaboration currently exists between the disaster management and conflict prevention communities despite obvious parallels in risk assessments, monitoring and warning, dissemination and communication, response capability and impact evaluation (Meier 2007).

6.5.1.6 Challenge: Enhance crop tolerance to abiotic stress

Abiotic stress of agricultural crops is expected to increase in most regions due to warmer temperatures, experienced both as episodic heat waves and mean temperature elevation, prolonged dry spells and drought, excess soil moisture, and salinity linked to higher evapotranspiration rates and salt intrusion. Expected temperature increases of 2-3° C by mid-century could significantly impair productivity of important staple crops of the developing world, such as wheat (citation). Also, one-third of irrigated agricultural lands worldwide are affected by high salinity, and the area of salt-affected soils is expected to increase at a rate of 10% per year (Foolad, 2004). The magnitude of these impacts could test AKST's capacity to achieve breakthroughs in germplasm improvement equivalent to the challenge at hand.

Option: Improve crop breeding potential for drought, salinity and heat tolerance. Advances in plant genomics, linked to the Arabidopsis model system, and the integration of genomics with physiology and conventional plant breeding could lead to the development of new varieties with enhanced tolerance to drought, heat, and salinity. Emerging genomic tools with future potential include whole-genome microarrays, marker-assisted selection using quantitative trait loci, bioinformatics, and microRNAs (Denby and Gehring, 2005; Edmeades et al., 2004; Foolad, 2006; Ishitani et al., 2004; White et al., 2004). Phenological adaptation, for example matching crop duration to available season length, is central to successful breeding efforts; thus conventional breeding, augmented with genomic tools, is a likely configuration of future plant breeding programs. An example of this would be the integration of phenotyping (differences in crop germplasm performance under different stress environments) with functional genomic approaches for identifying genes and mechanisms (Edmeades et al., 2004; Ishitani et al., 2004). Improvement in AKST, in the area of seasonal forecasting skill and in the use of remote sensing and other observational tools, could also be used to further support breeding programs, through better characterization of cropping environments.

Assessment: Future breakthroughs in understanding how crop plants respond to abiotic stress are very likely, given the scientific resources dedicated to investigating the Arabidopsis thaliana model system. For example, progress in genomics related to salt tolerance in Arabidopsis mutants has enhanced understanding of gene function, which could provide opportunities to exploit these mechanisms in crop species (Denby and Gehring, 2005; Foolad, 2004). However, direct extrapolation of single gene responses, gained through Arabidopsis studies, to functional abiotic tolerance of cultivated crop species could continue to be limited by differences in gene sequence between Arabidopsis and crop species (Edmeades et al., 2004; White et al., 2004). Moreover, gene expression in Arabidopsis changes when exposed to field conditions (Miyazaki et al., 2004, as reviewed by White et al., 2004), as would be expected given the influence of genotype by environment interactions. Genes for heat tolerance have been identified in a number of species, including rice, cowpea, and groundnut (citations), which is likely to provide future opportunities for heat-tolerance breeding.

Attaining more effective use of genomics for abiotic stress-tolerance breeding will depend on closer integration of this discipline with physiology, which could lead to better understanding of how genes confer changes in whole-plant biological function and agronomic performance (genotype-to-phenotype relationships) (Edmeades et al., 2004; White et al., 2004). However, the current imbalance between genomic research and field-based physiological studies, in favor of the former, could undermine future AKST progress towards developing new stress-tolerant germplasm. Lastly, future AKST would benefit from further expanding the scope of abiotic stress research to include more investigations of stress caused by mineral deficiencies and toxicities (Ishitani et al., 2004), as these factors strongly influence root development with implications for tolerance to climatic extremes (Lynch and St. Clair, 2004). For example, most tropical agricultural soils have high levels of exchangeable Al which stunt root system development. Bringing mineral stress tolerance more closely into the realm of abiotic stress research, while increasing the complexity of the breeding challenge, could possibly avoid short-circuiting progress on drought, heat and salinity breeding efforts when scaling up to actual field conditions where multiple and complex stresses occur.

AKST could also enhance adaptation through strengthening links between ex situ conservation, breeding, and farmers' groups. However, diversity for its own sake is not useful, as farmers retain varieties for specific traits, not for the sake of conservation (see Box n). If a new variety or set of varieties comes along, or of climate change renders older varieties less attractive, then they are likely to abandon these varieties.

Box *n*: The Importance of Crop Varietal Diversification as a Coping Strategy to Manage Risk

A study of traditional practices of conserving varieties of yam, Dioscorea sp., and of rice, Oryza glaberrima., was carried out in Ghana in 2003-2004 under an IPGRI-GEF-UNEP project on crop landraces in selected Sub-Saharan African countries (Gyasi et al. 2004). It identified 50 varieties of yam and 33 varieties of rice that are managed by a wide diversity of locally adapted traditional practices in the study sites located in the semi-arid savanna zone in the northern sector. The case study findings underscore the importance of crop varietal diversification as security against unpredictable rainfall, pest attack, fluctuating market and other such variable environmental and socio-economic conditions, not to mention its importance for modern plant breeding and wider use of farm resources, notably labor and the diversity of on-farm ecological niches.

6.5.1.7 Challenge: Diversify production systems

Diversification of agriculture systems is likely to become an important strategy for enhancing the adaptive capacity of agriculture to climate change.

Option: Options for AKST to support diversification include:

Improve seasonal and interannual climate forecasting skill and forecast dissemination to enhance decision support of crop and varietal selection;

Strengthen climate-crop modeling capacity related to long-term crop diversification planning;

Investigate the potential for improvement of underutilized traditional crops.

Assessment: Diversification strategies in the near term will need to be flexible, given that the disruptive impacts of climate change are projected to be experienced more in terms of increased variability, than as mean changes in climate (Easterling, 2005). Therefore, improved skill in predicting how short-term climate phenomena, such as the El Niño Southern Oscillation and the North Atlantic Oscillation, impact seasonal and interannual variability, and the timely dissemination of forecasts will be essential for farmer decisions about whether to grow high or low water-consumptive crops and use of drought-tolerant varieties (Adams et al., 2003; Stige et al., 2006). See Challenge 3, above, for an assessment of future opportunities and barriers for seasonal forecast.

Agro-ecological zone (AEZ) tools used by FAO (FAO, 2000) to determine crop suitability for the world's major ecosystems and climates has good potential to enhance AKST efforts at developing crop diversification strategies. The AEZ methodology, which combines crop modeling with environmental matching, would allow AKST to assess the suitability of particular crop combinations given future climate scenarios. However, the data sets that underlie AEZ need to be improved in order to realize the full potential of these tools for crop diversification. For example the current scale of the FAO world soil maps, at 1:5,000,000 needs finer resolution (FAO, 2000).

Agronomic and genetic improvement of underutilized, or so called 'lost', crops could provide a good opportunity for AKST to enhance agricultural diversification, particularly in Africa where approximately 2,000 underutilized food species are still consumed (NRC, 1996). Crops such as the legume Bambara groundnut (Vigna subterranean) and the cereal fonio (Digitaria exilis and Digitaria iburua) still figure prominently in the African diet. Fonio has very good prospects for semi-arid and upland areas because it is widely consumed, tolerates poor soil and drought conditions, matures very quickly (6-8 weeks), and has an amino acid profile superior to today's major cereals (NRC, 1996). Given that there have been no efforts to improve fonio's yield potential, AKST could play a key role in unlocking the genetic potential of this cereal through conventional breeding and biotechnology to address low yields, small seeds, and seed shattering (Kuta et al., 2003; NRC, 1996). Similar potential exists for Bambara groundnut (Azam-Ali, 2006; Azam-Ali et al., 2001), which is still cultivated from landraces. Research needs for underutilized crops include germplasm collection, marker assisted breeding, assessments of agronomic characteristics and nutritional content, development of improved processing technologies, and market analyses. While these crops cannot replace today's major cereals, their improvement could significantly enhance food security options for rural communities confronted with climate change.

6.5.2 Mitigation of greenhouse gas emissions from agriculture

6.5.2.1 Challenge: Achieve greater productivity with fewer GHG emissions.

AKST will be confronted with the challenge of needing to significantly increase agriculture output— to feed two to three billion more people and accommodate a growing urban demand for food— while slowing the rate of new GHG emissions from agriculture, and simultaneously adapting to the negative impacts of climate change on food production. Agriculture will have to become much more efficient in its production if it is to accomplish this without significantly increasing its climate forcing potential. All of this will have to be achieved in a future where agricultural crops may be in direct competition with crops grown for energy purposes.

Option: Reduce methane emissions from paddy rice production. There is good potential for achieving significant future reductions in CH_4 emissions from rice through improved water management. For example, CH_4 emissions from China's rice paddies has dropped by an average 40 percent over the last two decades, with an additional 20 to 60 percent reduction possible out to 2020, by combining the current practice of mid-season drainage with the adoption of shallow flooding, and by switching from urea to ammonium sulfate fertilizer, which impedes CH_4 production (DeAngelo et al., 2005; Li et al., 2005; 2006). There is also potential to achieve CH_4 reduction through integrating new insights of how the rice plant regulates CH_4

production and transport into rice breeding programs. (Kerchoechuen, 2005; Wassmann and Aulakh, 2000).

Option: Reduce nitrous oxide emissions from agriculture. Future avoidance of N_2O emissions from agriculture could be achieved by better matching fertilizer application with plant demand, through the use of site-specific nutrient management that only uses fertilizer N for meeting the increment not supplied by indigenous nutrient sources, split fertilizer application, use of slow-release fertilizer N and nitrification inhibitors (DeAngelo et al, 2005; Pampolino et al., 2007).

Option: Reduce methane and nitrous oxide emissions from livestock. Emerging technologies that could provide future options for reducing CH_4 and N_2O emissions from livestock include adding probiotics, yeasts, nitrification inhibitors, and edible oils to animal feed that reduce enteric CH_4 and N_2O emissions from livestock systems (Smith et al., 2007). Another opportunity to reduce CH_4 emissions from livestock operations would be to control methanogenic archae, microorganisms that live in the rumen and generate CH_4 during their metabolism. In Australia, farmers have been signing up for a major vaccination program to reduce methane production by sheep and cattle (New Scientist, 6 June 2001 issue) (check status).

Option: Improve adoption of C sequestration practices in agricultural systems. Improved management of agriculture and rangelands targeted at soil conservation, agroforestry, conservation tillage, agricultural intensification, and rehabilitation of degraded land can yield C sequestration benefits (Izaurralde et al., 2001; Lal, 2004). Carbon sequestration potential in soils is greatest on degraded soils (~1.2 billion hectares), especially those with relatively high clay content (Duxbury, 2005; Lal 2004).

Assessment: From a GHG mitigation standpoint, strategies that emphasize the avoidance of N2O and CH4 emissions are more economical than those that rely on modifying agricultural practices to enhance C sequestration, as long as the avoided emissions are tied to higher productivity, such as through increased energy efficiency and better factor productivity (Smith et al., 2007).

The robustness of soil carbon sequestration as a climate-change mitigation strategy has been questioned because soil carbon, like any other biological reservoir, may be reverted back to the atmosphere as CO_2 if the carbon sequestering practice (e.g., no till practice) were to be abandoned or practiced less intensively. It should be emphasized, however, that increasing soil organic matter through carbon sequestering practices contributes directly to the long-term productivity of soil, water, and food resources (Lal, 2004). Thus, it would seem unlikely that farmers would suddenly abandon systems of production that bring so many economic and environmental benefits. Other reports suggest that certain soil-carbon sequestering practices, such as no till, may increase N_2O emissions (Ball et al., 1999; Duxbury, 2005). This outcome, however, may be location specific (e.g., humid climatic conditions) as revealed by a comprehensive review of Canadian agroecosystem studies (Helgason et al. 2005). Globally, farmers continue to adopt no-till as their conventional production system. As of 2001, no-till agriculture had been adopted across more than 70 million hectares worldwide with major expansion in South America (e.g., Argentina, Brazil, and Paraguay) (Izaurralde and Rice, 2006). With an area under cropland estimated globally at 1.5 billion hectares, there exists a significant potential to increase the adoption of no till as well as other improved agricultural practices, which would bring along other environmental benefits such as improved soil quality and fertility, reduced soil erosion, and improved habitat for wildlife.

In addressing GHG mitigation from agriculture, AKST will need to develop strategies that carefully consider all potential GHG emissions. For example, efforts to reduce CH_4 emissions in rice can lead to greater N_2O emissions through changes in soil nitrogen dynamics (DeAngelo et al., 2005; Li et al. 2005; 2006; Wassmann et al., 2004; Yue et al., 2005). Similarly, conservation tillage for soil C sequestration can result in elevated N_2O emissions through increased fertilizer use and accelerated denitrification in soils (Ball et al., 1999; Duxbury, 2005). However, one of the most comprehensive long-term studies of GHG emissions across several land use practices in Michigan (Robertson et al., 2000) revealed that no-till agricultural methods had the lowest Global Warming Potential when compared to conventional and organic agricultural methods. (Global warming potential (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1). A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless.)

Many of the practices that avoid GHG emissions and increase C sequestration can also improve agricultural efficiency and the economics of production. For example, improving water and fertilizer use efficiency for avoidance of CH_4 and N_2O emissions also lead to gains in factor productivity (Gupta and Ashok, 2006; Hobbs et al., 2003) while practices that promote soil C sequestration can greatly enhance soil quality (Lal, 2005). There is significant scale for achieving this 'win-win' approach, with the approach largely determined by the size and input intensity of the production system, e.g. N-fixing legumes in smallholder systems and precision agriculture in large systems (Gregory et al., 2000).

On the policy front, the lack of institutionalized early warning systems that survey the localized impact of climate change on ecological and political crises inhibits the formulation of evidence-based interventions (Levy and Meier, 2004). High-quality and continuous information gathering is the nervous system of the humanitarian enterprise; without it, any form of principled action—whether now or in the future—is paralyzed (IFRC, 2003). Regrettably, little to no collaboration currently exists between the disaster management and conflict prevention communities despite obvious parallels in risk assessments, monitoring and warning, dissemination and communication, response capability and impact evaluation (Meier 2007).