# IAASTD GLOBAL REPORT
## CHAPTER 3

# IMPACTS OF AKST ON DEVELOPMENT AND SUSTAINABILITY GOALS

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## Key Messages

**1. Agriculture is multifunctional and goes far beyond food production.** Other important functions for sustainable development include provision of non-food products; provision of ecological services and environmental protection; advancement of livelihoods; economic development; creation of employment opportunities; food safety and nutritional quality; social stability; maintenance of culture and tradition and identity. However, the promotion and achievement of multifunctionality is hindered by a lack of systematic quantitative and other data that allow a complete assessment of the impacts of wider functions. Nevertheless, enhanced recognition of the wider functions of agriculture has prompted efforts towards developing integrated land use systems that deliver a diverse set of social, economic and environmental functions, and address the tradeoffs between them.

**2. Advances in AKST have enabled substantial gains in crop and livestock production, which have reduced levels of hunger and malnutrition.** World cereal production has more than doubled since 1961, with average yields per hectare also increasing around 150% in many high- and low-income countries, with the notable exception of most nations in sub-Saharan Africa. Substantial gains in crop and livestock production are due to advances in many types of AKST, including biotechnology (e.g. genetic gain, stress resistance), physical (e.g. fertilizer, irrigation, mechanization), policy (e.g. IPR, variety release processes), microfinance (e.g. credit, provision of inputs), education and communication (e.g. farmer-field schools), and market and trade (e.g. demand, incentives). More recently, modern biotechnology is starting to have an impact on production. Advances have also been made in fish breeding, tree improvement and in crop and livestock husbandry. All of these advances in agricultural production have contributed to the improvement of many farmers' livelihoods and to economic growth in developed countries, although large deficiencies remain. In real terms food has become cheaper and calorie and protein consumption have increased, resulting in lower levels of hunger. On a global scale, the proportion of people living in countries with an average *per capita* caloric availability of less than 2200 kcal per day dropped from 57% in the mid 1960s to 10% by the late 1990s.

**3. AKST has made some substantial positive contributions to different dimensions of livelihoods.** These include:

- increased incomes, reduced hunger and malnutrition, improved health and cognitive development, improved levels of education and increased employment opportunities, reducing vulnerability to drought, pest and disease outbreaks.
- increased access to water for domestic and productive uses with positive impacts on health, food and non-food production and environmental sustainability.

- improved relevance of AKST for different producer and consumer groups, through participatory approaches to research, extension and market assessment.
- improved support and integration of social and environmental sustainability (e.g. watershed management, community forestry management, IPM and strengthening of local seed systems) through participatory and community-based approaches to NRM at different scales.
- improved integration of gender and diversity concerns within AKST institutions, which has contributed to gender sensitive planning and awareness in AKST processes.

**4. Despite much progress in agricultural development, persistent challenges remain.** These include:

- *Uneven distribution of livelihood impacts*: The benefits from AKST have not been evenly distributed, varying between regions and agroecological zones, as well as between social groups. Industrialized regions have gained the most from innovations in AKST, while agroecological zones with severe biophysical constraints and marginalized social groups have benefited least. Levels of poverty, hunger, malnutrition and food insecurity still affect millions of people, particularly in SSA as well as parts of Asia, Latin America and Melanesia. Three billion people earn less than the purchasing power equivalent of US $2 per day. In some circumstances, especially in Africa, many of the poor have become ensnared in ‘poverty traps’ without sufficient financial resources to improve or sustain their food security or livelihoods. The distributional impact of AKST has been affected by rights and access to assets - land, water, energy resources, markets, inputs and finance, training, information and communications. Despite advances in gender awareness, access to AKST products and participation in AKST processes remain limited for women and for other marginalized groups. Only limited attention has been paid to issues of vulnerability and social exclusion, or to the interaction of AKST related opportunities with social protection policies.
- *Health and human nutrition*: Globally, over 800 million people are underweight and malnourished, while changes in diet, the environment and lifestyle worldwide have resulted in 1.6 billion overweight adults; this trend is associated with increasing rates of diet-related diseases such as diabetes and heart disease. Another cause of acute and long-term human health risks arises from the misuse of toxic agrichemicals.
- *Environmental sustainability*: Agricultural use of natural resources (soils, freshwater, air, carbon-derived energy) has, in some cases, caused significant and widespread degradation of land, freshwater, ocean and atmospheric resources. Estimates suggest that resource impairment negatively influences 2.6 billion people. In many poor countries (and in marginalized communities within countries), many farmers lack access to the appropriate management interventions required to restore and sustain productivity. In addition to forest clearance and burning, the growing reliance on fossil fuels in agriculture has increased emissions of ‘greenhouse gases.’

**5. In many instances, AKST has begun to address sustainability challenges with strategies that recognize the production, livelihoods, and ecosystem service functions required for achieving sustainable agricultural systems that span biophysical, socioeconomic and cultural diversity.** The consequences of population growth and economic expansion have been a reduced resource base for future agriculture; now there are pressing needs for new agricultural land and water resources. In recent decades the development of integrated pest/water/nutrient management practices, crop/livestock systems, and crop/legume mixtures has contributed greatly to increased agricultural sustainability, but further progress is needed, especially to combat declining soil fertility. While fertilizer amendments restore fertility efficiently, many poor farmers are without the means to buy fertilizers. Consequently they suffer from a 'yield gap' (the difference between crop yield potential and yield achieved). Agroforestry offers them a partial solution: biological nitrogen-fixation by leguminous trees/shrubs and crops can substantially increase crop yields. The integration of trees into field systems and by re-planting watersheds, riparian and contour strips, also diversifies and rehabilitates the farming system, restoring soil organic matter, sequestering carbon in the biomass, improving water percolation and microclimate, reducing radiation losses to the atmosphere, and promoting biodiversity through the development of an agroecological succession. There are many indigenous tree species that have the potential to play these important ecological roles and also produce marketable food, fodder, and non-food products. In this way, the ecological services traditionally obtained by long-periods of unproductive fallow are provided by productive agroforests yielding a wide range of food and non-food products. Some of these trees species are currently the subject of participatory domestication programs using local knowledge. Domestication is aimed at promoting food sovereignty, generating income and employment and enhancing nutritional benefits. Consequently, this approach brings together AST with Traditional Knowledge as an integrated package capable of helping to meet development and sustainability goals.

**6. Sustainable agriculture is more complex and knowledge intensive than ever before, covering sociocultural, ecological and economic dimensions. To be effective at using AKST to meet development and sustainability goals requires a wide range of actors and partnerships, and arrangements that realize the synergies between different forms of agriculture; between agriculture and other sectors; between different disciplines and between local and global organizations.** Examples of measures that have contributed to realizing synergies include:

- the development of international regulatory frameworks on IPR, trade, and the environment. .
- collective action at levels not usually addressed through public action or market processes.

- linking multiple sources of knowledge created through the engagement of multiple stakeholders in AKST processes, including farmer organizations, civil society groups, the private sector and policy makers, as well as public sector organizations.

There is a growing recognition that the institutional, policy, financial, infrastructural and market conditions required for AKST to help meet development and sustainability goals are an intrinsic part of innovation processes. This has encouraged a growing emphasis on forging partnerships and linkages, which is beginning to have positive results. Much remains to be learned about the effective development and functioning of these partnerships to create an effective combination of different disciplines and knowledge traditions; overcome the separation of formal organizations involved in AKST and to institutionalize broader consultation processes among stakeholders with diverse interests, professional and organizational cultures, funding arrangements and capacity.

**7. Since the mid 20th Century, there have been two relatively independent pathways to agricultural development: globalization and localization.** Globalization, which initiated in developed countries, has dominated formal AKST and has been driven by public-sector agricultural research, international trade and marketing policy. Localization has come from civil society and has involved locally based innovations, including value-addition, that meet the needs of local people and communities. Localization addresses the integration of social and environmental issues with agricultural production, but has lacked a range of market and policy linkages in support of new products and opportunities. Some current initiatives are drawing the two pathways together through public/private partnerships (e.g. fair-trade tea/coffee, forestry out-growers) involving global companies and local communities in the implementation of new regulatory frameworks and agreements that offering new paradigms for economic growth and development. Mobilizing and scaling up locally appropriate AKST in ways that integrate agricultural production with economic, social and environmental sustainability, permits localization and globalization to play complementary roles.

## 3.1 Methodology

The goals of this Assessment reflect an evolution of the concept of agriculture from a strong technology-oriented approach at the start of the Green Revolution to today's more human and environment-oriented paradigm. Assessing the biophysical impacts of AKST is simpler than assessing the social impacts, because of differences in complexity, and the greater emphasis on agronomic research, much of which has been on-station, rather than on-farm. This evolution of agriculture is reflected in the expansion of the CGIAR, including Centers with a greater focus on natural resources systems, and more recently, on holistic and integrated approaches, including the livelihoods of poor farmers. This integration of technological advances with socially and environmentally sensitive approaches has not occurred uniformly across all sectors of AKST.

The preparation of this Chapter started with a review of the international literature (journals, conference proceedings, the reports of many and various organizations from international and nongovernmental development agencies, international conventions and development projects, and the internet). The information from this literature was then used to develop statements about the impacts and sustainability of AKST in the context of development and sustainability goals (see Chap 1).

The main criteria used to assess the positive and negative impacts (including risks associated with technologies) of AKST were:

- Social sustainability – effects on livelihoods, nutrition and health, empowerment, equity (beneficiaries – including landless and labor), gender, access.
- Environmental sustainability – effects on natural capital, agroecosystem function, climate change.
- Economic sustainability - poverty, trade and markets, national and international development.

Levels of certainty were attributed to impact and sustainability statements based on evidence found in the international literature and the expert judgment of the authors. This certainty was associated with the range of impacts reported and to the appropriate measures of scale and specificity (Table 3.1).

**[Insert Table 3.1]**

## 3.2 Assessment and Analysis of AKST Impacts

In this subchapter we present Impact Statements (in bold), analyzed and quantified as explained above (Table 3.1).

### *3.2.1 Agriculture productivity, production factors and consumption*

Since the mid-20th Century, there have been two relatively independent pathways to agricultural development. The first, which has dominated formal AKST, was initiated globally and has involved public-sector agricultural research coordinated by the International Agricultural Research Centres (IARCs) of the CGIAR.

3.2.1.1 Food production, consumption, and human welfare

The improvement of farm productivity was the major outcome of the Green Revolution, especially in the early years, Large benefits from resulted from the application of AKST in crop and livestock breeding, improved husbandry, increased use of fertilizers, pesticides and mechanization. However, these benefits were accompanied by some environmental issues.

**Modern agricultural science and technology has positively affected a large number of people worldwide.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, D | A | 0 to +5 | G | Especially in industrial and transitional countries |

Despite large increases in population (Chap 1), agricultural systems have provided sufficient food resources to reduce undernourishment rates by about 50% in Asia/Pacific and Latin American/Caribbean since 1970. Large increases in agricultural production of vegetables, roots and tubers, cereals, fruits and latterly pulses, have been made possible through genetic improvement, soil fertility management, irrigation, pesticides and mechanization (Salokhe et al., , 2002; Figure 3.1). On a global scale, AKST has increased *per capita* production of calories, fats/oils, proteins and micronutrients (Evenson and Gollin, 2003ab). For example, available caloric availability has increased from 2360 kcal/person/day in the mid-1960s to 2803 kcal/person/day in the 1997/99 (Bruinsma, 2003). At present, 61% of the world's population consume >2700kcal per day. Prices for staple foods have also declined (Bruinsma, 2003), benefiting many poor since they spend a large portion of their income on food. However, AKST benefits have been unevenly realized among and within regions and some estimates suggest that around a third of humanity has not been affected by modern agricultural science.

**[Insert Figure 3.1]**

**Agricultural science and technology has had positive impacts on the productivity (yield per unit area) of staple food crops, but these gains have not been universally realized.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, D | A | +1 to +5 | G | Especially in industrial and transitional countries |

The cereal staples maize, rice, and wheat contribute around 60% of the caloric energy for humans on the global scale (Cassman et al., 2003). Among industrialized countries and in the developing regions of Asia and Latin and Central America (LAC), average cereal yields have sustained annual rates of increase (43 to 62 kg $ha^{-1}$ $yr^{-1}$), and have more than doubled in absolute terms since the 1960s (Figure 3.2). In contrast, in developing countries in Africa the average cereal yields have increased at a rate of 10 kg $ha^{-1}$ $yr^{-1}$ and productivity levels are about one-half of those achieved in industrialized countries in the early 1960s. In sub-Saharan Africa (SSA) approximately 66% of the crop production increase since 1961 is linked to area expansion. These broader trends mask significant differences among the grain staples. For example, in industrialized countries, maize productivity has grown at average rate of 122 kg $ha^{-1}$ $yr^{-1}$, increasing from a base of 3 tonnes $ha^{-1}$ in 1961 to nearly 8 tonnes $ha^{-1}$ in 2005. In 1961, maize productivity was approximately 1 tonne $ha^{-1}$ in developing countries. Since then, maize yields have steadily increased in developing regions of Asia (72 kg $ha^{-1}$ $yr^{-1}$), demonstrated intermediate growth in Central America (37 kg $ha^{-1}$ $yr^{-1}$), but achieved only slow growth among developing countries in Africa (12 kg $ha^{-1}$ $yr^{-1}$). A major reason for this, especially in Africa, has been the lack of investment in public and private sector plant breeding programs (Morris, 2002). Similar trends are evident in rice and for other major commodities such as vegetables, roots, pulses and tubers (Figure 3.2).

**[Insert Figure 3.2]**

**Recently horticulture, including fruit production, has been the fastest growing food sector worldwide**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, D | B | +1 to +3 | G | Especially China |

Horticulture production has increased from 495 million tonnes in 1970 to 1379 million tonnes in 2004 (178%) (FAOSTAT, 2007). The vegetable subsector grew at an annual average rate of 3.6% during 1970-2004, from 255 million tonne in 1970 to 876 million tonnes in 2004 (Ali, 2006). Most of this increased production came from area expansion with productivity per unit area increasing at less than 1% from 1970-2004. The slow improvement in the yield of horticulture crops suggests comparatively low investments in horticultural research. During 1970-2004, 52% of the increase in horticulture production came from China, 40% from all other developing countries, and remaining 8% from developed countries (Ali, 2006). This increase is having significant positive effects on income, employment, micronutrient availability and health of people in poor countries. Moreover, the share of horticulture products in trade, especially from developing countries, has increased (Ali, 2006).

**Global production and consumption of livestock products have been growing dramatically over the last few decades.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, D | A | 0 to +3 | G | Wide applicability |

From 1979 to 2003, global meat production nearly doubled to 260 million tonnes (FAOSTAT, 2007). Among developing countries, those with large populations and rapidly growing economies (e.g., China, Brazil and India) accounted for over 50% of meat and milk production in 2005. Consumption of livestock products has also increased sharply, in part due to rising incomes and increasing urbanization in several parts of the developing world. Between 1962 and 2003 *per capita* meat consumption grew by a factor of 2.9, and milk by 1.7 in developing countries (Steinfeld et al., 2006; FAO, 2006a).

**Global fish production (wild harvest and aquaculture) has increased by about 230% between 1961 and 2001**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H | B | 0 to +4 | G | Worldwide |

Between 1961 and 2001, global fish production (wild harvest and aquaculture) for all uses increased by about 230% from 39.2 million to nearly 130 million tonnes. Developing countries supply 75% of the volume and 50% of the value of the global fish trade (Kurien, 2004). Together the developing countries of Asia form the largest fish producer, with production reaching 71.2 million tonnes in 2001 (FAOSTAT, 2005). Aquaculture currently provides approximately 40% of the world's total food fish supply (Delgado et al., 2003ab; Kurien, 2004). Technological breakthroughs in aquaculture, triggered by private sector growth, increased demand for high-value fish in the world market and simultaneous changes in international laws, treaties and institutions, contributed to the rapid growth in fish supply (Ahmed and Lorica, 2002).

*3.2.1.1.1 Trends in resource use (land, water, genetic resources, fertilizer, pesticides and mechanization)*

**Globally, land reserves have been severely depleted by cultivation**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E, D | A | -1 to +2 | G | Worldwide |

Africa and Latin American do have significant tracts of undeveloped land that could be cultivated, but estimates suggest that only a small fraction these areas (7% Africa, 12% LAC) are free from the types of severe soil constraints that limit profitable and sustainable production (Wood et al., 2000). Moreover, many of the remaining undeveloped areas are of regional and global importance for biodiversity and ecosystem services (Bruinsma, 2003). The need to preserve natural areas and to avoid production on marginal lands (e.g., highly erodible hillslopes) provides strong incentives for advancing agricultural production through yield intensification (i.e. production per unit area) rather than area expansion.

**The breeding and dissemination of Modern Varieties (MV) has had a major impact on food production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | A | -2 to +5 | G | Widespread applicability |

The breeding and dissemination of Modern Varieties with greater yield potential, better pest and disease resistance and improved organoleptic quality have, in conjunction with irrigation, fertilizer, pesticides and mechanization, had a major impact on food production (Figure 3.1). Modern Varieties, especially of cereals but also of root, protein and horticultural crops, have been widely adopted; Asia grows modern cereal varieties on 60- 80% of the cultivated area (Evenson and Gollin, 2003a). Modern Varieties are also widely grown in Latin America but there has been less impact in sub-Saharan Africa and CWANA. Other than in CWANA there has been little impact of Modern Varieties on protein crops (mostly annual legumes).

**Evidence relating farm size to productivity and efficiency is weak.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | C | -4 to +4 | G | Variable |

Farms operated by small-scale producers are typically more efficient the smaller they are (Feder et al., 1988; Place and Hazell, 1993; Deininger and Castagnini, 2006). However, in large-scale mechanized farming economies of scale are important. For example, some regionally specific research has concluded that productivity and efficiency are positively related to farm size (Yee et al., 2004; Hazarika and Alwang, 2003), although there is also evidence that some large-scale mechanized farms are less efficient than smaller family farms (Van Zyl, 1996). The lack of clarity about the relationship between farm size and productivity and efficiency (Sender and Johnston, 2004) suggests confounding factors, such as land quality, and access to labor, markets, sources of credit and government farm policies (Van Zyl, 1996; Gorton and Davidova, 2004; Chen, 2004). For example, land per capita has been found to be a major determinant of overall household income (Jayne et al., 2003). Good management, on large- and small-scale farms, may be the most important factor affecting production efficiency. Typically, large-scale farmers with financial resources intensify agrichemical inputs and seek economies of scale, while resource poor small-scale farmers reduce inputs, diversify, and seek risk aversion (Leakey, 2005a). Interestingly, it is often among the latter group that some of the best examples of sustainable agriculture are found, especially in the tropics (Palm et al., 2005b).

**Globally there has been an extensive increase in irrigated areas, but investment trends are changing**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | B | -1 to +5 | G | Globally except SSA |

Since 1961, the area of irrigated land has doubled to 277 million ha (in 2000) – about 18% of farmed land, funded initially by investments by international development banks, donor agencies, and national governments but later increasingly by small-scale private investments. Irrigation was essential to achieving the gains from high-yielding fertilizer-responsive crop varieties. Approximately 70% of the world's irrigated land is in Asia (Brown, 2005), where it accounts for almost 35% of cultivated land (Molden et al., 2007a). Forty percent of the world cereal production is from irrigated land and as much as 80% of China's grain harvest comes from irrigated land. By contrast, there is very little irrigation in sub-Saharan Africa. Trends have changed from the 1970s and early 1980s when donor spending on agricultural water reached a peak of more than US $1 billion a year. Funding fell to less than half that level by the late 1980s; benefit-cost ratios deteriorated; and as falling cereal prices and rising construction costs highlighted the poor performance of large-scale irrigation systems, opposition mounted to the environmental degradation and social dislocation sometimes caused by large dams. Today, there appears to be consensus that the appropriate scale of infrastructure should be determined by the specific environmental, social, and economic conditions and goals with the participation of all stakeholders (Molden et al., 2007a).

**Increased fertilizer use is closely associated with crop productivity gains in regions that have been most successful at reducing undernourishment**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | +2 to +5 | G | Especially in Asia |

On a global scale, total fertilizer consumption has increased from approximately 31 million in 1961 to 142 million tonnes in 2002 (FAOSTAT, 2007). From almost no use in the early 1960s, total fertilizer consumption rates in the developing countries of Asia (140 kg $ha^{-1}$ $yr^{-1}$) now exceed those in industrialized nations (FAOSTAT, 2006) and have been a principal driver of improved crop productivity. In sub-Saharan Africa where cereal productivity has increased only modestly since the 1960s, average fertilizer consumption remains exceptionally low at under 20 kg $ha^{-1}$ $yr^{-1}$ (FAOSTAT, 2006). For cereal crops, approximately 50% of the yield increases observed after the introduction of modern crop varieties in countries such as India can be attributed to increased fertilizer use (Bruinsma, 2003). However, there is also evidence of declining efficiency of nitrogen applications in cropping systems.

**Tractors and other sources of mechanization are increasingly important to agriculture in developing countries**, **but many systems remain dependent on traditional forms of human and animal power.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -1 to +3 | G | Developing countries |

In developing countries, human, draft animal, and tractor power are used in approximately equivalent proportions in terms of total land under cultivation. There are, however, significant differences between and within countries and between regions and different types of agricultural systems. In SSA, about two-thirds of all agricultural land is cultivated by hand, whereas in LAC approximately 50% of the land is mechanically cultivated (Bruinsma, 2003). Although it is difficult to directly establish cause and effect relationships between single classes of assets and human welfare, it is generally recognized that households with animal or mechanical power tend to have better crop yields, more opportunities to pursue off-farm employment, and greater food security (Bishop-Sambrook, 2004).

**Pesticide use is increasing on a global scale, but increases are not universally observed; several of the most hazardous materials are being phased out in well-regulated markets.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | C | -5 to +4 | G | Developed and developing countries |

In constant dollars, global expenditures on agricultural pesticide imports has increased more than 1,000% since 1960 (Tilman et al., 2001) with some estimates placing recent growth rates for pesticide use at between 4.0 and 5.4% per annum (Yudelman et al., 1998). There are exceptions to these trends, particularly in OECD countries. For example, in the U S, agricultural pesticide use declined significantly after peaking in the late 1970s and has remained relatively constant since the 1990s (Aspelin, 2003). Moreover, regulatory and technological advances have, in some cases, resulted in the phase-out of particularly toxic organic compounds and the introduction of pesticides with lower non-target toxicity, which are less persistent in the environment and can be applied at lower rates (MA, 2005; Aspelin, 2003).

**Total factor productivity has increased worldwide, with some regional variation**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | C | -1 to +3 | G | Especially in intensive systems |

Total Factor Productivity (TFP), i.e. the efficiency with which all the factors of agricultural production (land, water, fertilizer, labor, etc.) are utilized, has improved over the last fifty years (Coelli and Rao, 2003). The index of TFP for world agriculture has increased from 100 in 1980 to 180 in 2000. The average increase in TFP was 2.1% per year, with efficiency change contributing 0.9% and technical change 1.2% (Coelli and Rao, 2003). The highest growth was observed in Asia (e.g. China 6%) and North America and the lowest in South America followed by Europe and Africa. However, a positive trend does not necessarily imply a sustainable system since rapid productivity gains from new technologies may mask the effects of serious resource degradation caused by technology-led intensification, at least in the short to medium-term (Ali and Byerlee, 2002).

*3.2.1.1.2 Agriculture has impacts on natural capital and resource quality*

**In regions with the highest rates of rural poverty and undernourishment, depletion of soil nutrients is a pervasive and serious constraint to sustaining agricultural productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -1 to -5 | R | SSA, ESAP |

To sustain long-term agricultural production, nutrients exported from the agroecosystem by harvest and through environmental pathways (e.g. leaching, erosion) must be sufficiently balanced by nutrient inputs (e.g. fertilizer, compost, atmospheric deposition, *in situ* biological nitrogen fixation). In the tropical countries where shifting agriculture is the traditional approach to regenerating soil fertility, increasing population pressure has resulted in shorter periods of fallow and often severe reductions in soil stocks of organic carbon and nutrients (Palm et al., 2005a). Nutrient depletion is particularly acute in many of the continuous cereal production systems on the Indian sub-Continent, Southeast Asia, and sub-Saharan Africa, especially since many of the soils in these regions have low native fertility (Cassman et al., 2005). With reduced land availability for fallows, low use of fertilizer amendments, and (in some circumstances) high rates of erosion, many soils in sub-Saharan Africa are highly degraded with respect to nutrient supply capacity (Lal, 2006; Vanlauwe and Giller, 2006). It has been estimated that 85% of the arable land in Africa (ca. 185 million ha) has net depletion rates of nitrogen, phosphorous, and potassium (NPK) that exceed 30 kg $ha^{-1}$ $yr^{-1}$ (Henao and Baanante, 2006) with 21 countries having NPK depletion rates in excess of 60 kg $ha^{-1}$ $yr^{-1}$.

**In high-yielding agriculture, the application of modern production technologies is often associated with environmental damage. In some cases, this damage is most attributed to inappropriate policies and management practices rather than to the technologies *per se.***

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | 0 to -5 | G | Widespread |

The adoption of MVs and yield enhancing technologies like inorganic fertilizer use and irrigation have been linked to a loss of biodiversity, reduced soil fertility, increased vulnerability to pests/diseases, declining water tables and increased salinity, increased water pollution, and damage to fragile lands through expansion of cropping into unsuitable areas. A detailed assessment of the environmental impacts associated with productivity enhancing technologies concluded that empirical evidence for these associations only exists for three scenarios - salinity, lower soil fertility, and pesticides and health (Maredia and Pingali, 2001). Furthermore, many of the best documented environmental costs from agriculture are related to the mis-application of technologies or over-use of resources rather than to the direct impacts of technology *per se*. Examples of this include the subsidy-driven exploitation of groundwater for irrigation (Pimentel et al., 1997) and a lack of a complementary investment in drainage to reduce salinity problems in irrigated areas with poorly-drained soils (NAS, 1989). Some authors highlight the need for a counterfactual argument, i.e. what would have happened in the absence of yield enhancing technologies (e.g. Maredia and Pingali, 2001). For example, how much extra land would be required if yield levels had not been enhanced? Estimates suggest that at 1961 yield levels, an extra 1.4 billion ha of cultivated land would be required to match current levels of food production (MEA, 2005).

**Resource-conserving technologies may reduce or eliminate some of the environmental costs associated with agricultural production with mixed results in terms of yield and overall water use.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, L, E, D | A, B | -2 to +5 | G | Widespread |

Resource-conserving technologies (RCT) such as reduced tillage and conservation agriculture systems have been widely adopted by farmers in the last 25 years. For example, no-till systems now occupy about 95 million ha, mostly in North and South America (Derpsch, 2005), with current expansion in the Ingo-Gangetic Plain of South Asia (Hobbs et al., 2006; Ahmad et al., 2007). In general, no-till systems are associated with greatly reduced rates of soil erosion from wind and water (Schuller et al., 2007), higher rates of water infiltration (Wuest et al., 2006), groundwater recharge, and enhanced conservation of soil organic matter (West and Post, 2002). Yields can be increased with these practices, but while the physical structure of the surface soil regenerates, there can be significant interactions with crop type (Halvorson and Reule, 2006), disease interactions (Schroeder and Paulitz, 2006), surface residue retention rates (Govaerts et al., 2005), and time since conversion from conventional tillage. Other resource conserving technologies such as contour farming and ridging are also useful for increasing water infiltration, and reducing surface run-off and erosion (Cassman et al., 2005; Habitu and Mahoo 1999; Reij et al. 1988). Evidence from Pakistan (Ahmad et al., 2007) suggests that while RCT results in reduced water applications at the field scale, this does not necessarily translate into reduced overall water use as RCT serves to recharge the groundwater and then be reused by farmers through pumping. The increased profitability of RCTs also results in the expansion of the area cropped.

**Modern agriculture has had negative impacts on biodiversity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | 0 to -5 | G | Widespread |

The promotion and widespread adoption of modern agricultural technologies, such as modern crop and livestock varieties and management practices, has led to a reduction in biodiversity, though this is contested for some crops (Maredia and Pingali, 2001; Dreisigacker et al., 2003; Smale et al., 2002). Although biodiversity may have been temporally reduced, genetic diversity is now increasing in major cereal crops. The CGIAR and other research centers hold in trust large numbers of crop plant accessions representing diversity.

**Land degradation is a threat to food security and rural livelihoods through its effects on agricultural production and the environment.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -1 to -5 | G | Especially severe in the tropics |

Land degradation typically refers to a decline in land function due to anthropogenic factors such as overgrazing, deforestation, and poor agricultural management (FAO/UNEP, 1996; www.unep.org/GEO/geo3). Degradation affects 1.9 billion ha and 2.6 billion people and, with varying degrees of severity (Figure 3.3), and potential for recovery, encompasses a third of all arable land with adverse effects on agricultural productivity and environmental quality (UNEP, 1999; Eswaran, 1993; Esawaran et al., 2001, 2006). Inadequate replenishment of soil nutrients, erosion, and salinization are among the most common causes of degradation (Nair et al., 1999; Guerny, 1995). The GEO Report foresees that by 2030 developing countries will need 120 million additional hectares for agriculture and that this will been to be met by commercial intensification and extensification, using lands under tropical forest and with high biodiversity value (Ash et al., 2007). The restoration of degraded agricultural land is a much more acceptable option. Restoration techniques are available, but their use is inadequately supported by policy.

The recovery potential of degraded land is a function of the severity, and form of degradation, resource availability and economic factors. Soil nutrient depletion can be remedied by moderate application of inorganic fertilizer or organic soil amendments, which can dramatically improve grain yields in the near-term, although responses are sensitive to factors such as soil characteristics (Zingore et al., 2007). Low-input farming systems, which are characterized by diversification at the plot and landscape scale can reverse many of the processes of land degradation, especially nutrient depletion (Cooper *et al*., 1996; Sanchez and Leakey, 1997; Leakey *et al*., 2005a).

**[Insert Figure 3.3]**

**Global livestock production is associated with a range of environmental problems and also some environmental benefits**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E, D | A | -3 to 0 | G | Widespread applicability |

The environmental problems associated with livestock production include direct contributions to greenhouse gas emissions from ruminants and indirect contributions to environmental degradation due to deforestation for pastures, land degradation due to overstocking, and loss of wildlife habitats and biodiversity (FAO, 2006d). Additionally, livestock require regular access to water resources, which they deplete and contaminate. On the other hand, extensive pastoral systems like game ranching, are more compatible with biodiversity conservation than most other forms of agriculture (Homewood and Brockington, 1999).

**Intensive agricultural systems can damage agroecosystem health.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | A | -1 to -5 | G | Most agricultural systems |

Agroecosystem health is important for nutrient, water and carbon cycling, climate regulation, pollination, pest and disease control and for the maintenance of biodiversity (Altieri, 1994; Gliessman, 1998; Collins and Qualset, 1999). Intensive production systems, such as the rice-wheat system in the Punjab, have led to deterioration in agroecosystem health, as measured by soil and water quality (Ali and Byerlee, 2002). This deterioration has been attributed to unsustainable use of fertilizer and irrigation, though whether this is due to intensification *per se* or to mismanagement is unclear. For example, in China, grain yield would have increased by 5% during 1976-89 given less erosion and less soil degradation (e.g., increased salinity) (Huang and Rozelle, 1995). More evidence is needed about the relationships between total factor productivity and long-term agroecosystem health. In some cases, intensified production on prime agricultural land may reduce negative impacts on ecosystem health by reducing the incentive to extend production onto marginal lands or into natural areas (e.g. highly erodible hillslopes).

**Poor irrigation management causes land degradation with negative impact on livelihoods.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | -1 to -3 | R | Especially in the dry tropics |

Irrigation increases crop productivity in dry areas, but can result in land degradation. Poor drainage and irrigation practices have led to waterlogging and salinization of roughly 20% of the world's irrigated lands, with consequent losses in productivity (Wood et al., 2000). While livelihoods have improved through increased production and employment, demands for irrigation water have degraded wetland biodiversity (Huber-Lee and Kemp-Benedict, 2003 quoted in Jinendradasa, 2003). Poorly conceived and implemented water management interventions have incurred high environmental and social costs, including inequity in benefit allocation and loss of livelihood opportunities. Common property resources such as rivers and wetlands, important for poor fishers and resource gatherers, have been appropriated for other uses, resulting in a loss of livelihood opportunities. Communities have been displaced, especially in areas behind dams, without adequate compensation. A large proportion of irrigation's negative environmental effects arise from the diversion of water away from natural aquatic ecosystems (rivers, lakes, oases, and other groundwater dependent wetlands). Direct and indirect negative impacts have been well documented, including salinization, channel erosion, declines in biodiversity, introduction of invasive alien species, reduction of water quality, genetic isolation through habitat fragmentation, and reduced production of floodplain and other inland and coastal fisheries.

**In some river basins, water scarcity due to irrigation has become a key constraint to food production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | -1 to -5 | R | Especially severe in the dry tropics |

50 years ago water withdrawal from rivers was one third of what it is today, with 70% of freshwater withdrawals (2,700 cubic kilometers – 2.45% of rainfall) attributable to irrigated agriculture (CA, 2007). About 1.6 billion people live in water scarce basins. Water availability is a worldwide problem (Figure 3.4) despite a decline in water withdrawal for agriculture over the past 20 years (FAO AQUASTAT, 2007) in developed (58 to 39%) and developing countries (76 to 71%) - a decline of 69 to 61% globally (FAOSTAT, 2006). In both irrigated and rainfed areas, a decline in water available for irrigation, without compensating investments and improvements in water management and water use efficiency, has been found to reduce production with a consequent increase in international cereal prices and negative impacts on low-income developing countries (Rosegrant and Cai, 2001). Global investment in water distribution systems for agriculture has declined relative to other sectors during recent decades.

**[Insert Figure 3.4]**

**Agriculture contributes to degradation and pollution of water resources**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | A | -1 to -5 | G | Most agricultural systems |

Traces of the herbicide ‘Atrazine’ and other pesticides are routinely documented in shallow ground and surface waters in industrialized countries. Recent surveys in the U.S. suggest that pesticides concentrations exceed human health and wildlife safety standards in approximately 10% of streams and 1% of groundwater wells (USGS, 2006). In intensive agricultural regions, streamwater nitrogen concentrations have been found to be nearly nine times higher than downstream from forested areas (Omernik, 1977). Increasing concentrations of nitrate nitrogen in the Mississippi River have also been linked to hypoxic conditions in the Gulf of Mexico (Rabalais et al., 1996).

*3.2.1.1.3 Impacts on diet and health*

**Patterns of food consumption are becoming more similar throughout the world,**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S | B | -2 to +2 | R | Widespread in the tropics |

The Green Revolution did not focus on nutrient-rich foods like fruits, vegetables, legumes and seafood. The focus on cereals led to an increased *per capita* consumption of cereals, while in most developing countries, consumption of vegetables remained far below the minimum requirement level of 73 kg per person (Ali and Abedullah, 2002). Likewise, *per capita* consumption of pulses in south Asia fell from 17 kg in 1971 to 12 kg in 2003 (Ali et al., 2005). Recently, however, vegetable production has increased in developing countries, through public-private collaboration in the introduction of modern varieties and technologies. The replacement of traditional plant based diets with increased consumption of more energy-dense, nutrient-poor foods with high levels of sugar and saturated fats in all world regions (Popkin, 2003) has been driven by increased incomes and other factors such as changes in food availability, and retail and marketing activities. Increased protein consumption (e.g., meat and dairy products) is occurring in developing countries, but high costs limit consumption primarily to the urban elite.

**The application of modern AKST has led to a decline in the availability and consumption of traditional foods.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, D | B | -2 to -4 | R | Widespread in the tropics |

In the past, many traditional foods were gathered from forests and woodlands, which provided rural households with food and nutritional security. With the loss of habitat through deforestation, population growth, increased urbanization and poverty and an emphasis on staple food cultivation, this wild resource has diminished. In addition, improved access to other food crops and purchased foods (Arnold and Ruiz Pérez, 1998) have contributed to the trend towards diet simplification, reduced fresh food supply, and disappearance of nutrient rich indigenous food. This simplification has had negative impacts on food diversity and security, nutritional balance, and health. Indigenous fruits and vegetables have been given low priority by policy makers, although they are still an important component of diets, especially in Africa.

**Supplies of nutritious traditional food are in decline, but reversible**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S | B | -2 to -4 | R | Widespread in the tropics |

Deforestation and increasing pressures from urban infrastructure have reduced the fresh sources of food supply from forests and urban gardens (Ali et al., 2006). Projects to reverse this trend promote traditional foods as new crop plants (Leakey, 1999a; Leakey et al., 2005a) and encourage their consumption. For example in Zambia, the FAO Integrated Support to Sustainable Development and Food Security Program (IP-Zambia) is promoting the consumption of traditional foods (www.fao.org/sd/ip).

### 3.2.1.2 Biotechnology: conventional breeding and tissue culture

The modification of plants and animals through domestication and conventional plant breeding (i.e. excluding use of nucleic acid technologies and genetic engineering) has made a huge contribution to food production globally: the Green Revolution for plants, the Blue Revolution for fish, and the Livestock Revolution.

#### *3.2.1.2.1 Impact of modern varieties of crops (including trees) and improved livestock breeds*

The impact of domestication and conventional breeding, especially in annual crop plants, has been well documented. Modern varieties and breeds have had positive impacts on yield and production, especially where environments have been favorable and management has been good. However, there have also been some negative effects on the environment and on biodiversity. There is also some concern that on-station and on-farm yields are stagnating.

**Agriculture is dependent on very few species of animals and plants.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E | A, B | -2 to +5 | G | Wide applicability |

Agriculture began with the domestication of wild animals and plants. About 1000 plant species have been domesticated resulting in over 100 food and 30 non-food crops (fiber, fodder, oil, latex, etc., excluding timber). Approximately 0.3% of the species in the plant kingdom have been domesticated for agricultural purposes (Simmonds, 1976) and 4.1% for garden plants (Bricknell, 1996). These proportions rise to 0.5 and 6.5% respectively if limited to the higher plants (angiosperms, gymnosperms and pteridophytes) of which there are some 250,000 species (Wilson, 1992), but are small when compared with the 20,000 edible species used by hunter-gatherers (Kunin and Lawton, 1996). A similar pattern has occurred in animals and fish, with only a small proportion of the species traditionally consumed domesticated through AKST. Over the last 50-60 years plant and animal breeding was a major component of the Green Revolution.

**Overall, the impacts of the Green Revolution have been mixed.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | C | 0 to -3 | G | Mainly small-scale agriculture |

Positive impacts on yield have been achieved in Latin America with an increase of 132% (36% from improved varieties and 64% from other inputs) on 32% less land (Evenson and Gollin, 2003a). Negative effects on yield occurred in sub-Saharan Africa even though overall yield increased 11% (130% coming from improved varieties and -30% from other inputs), since 88% more land was used). In SSA and CWANA, MVs were released but not adopted throughout the 1960s and 70s (Evenson, 2003). In some cases, MVs lacked desired organolepic qualities or were not as well adapted as Traditional Varieties (TVs). However, in many cases the lack of adoption resulted from inadequate delivery of seeds to farmers (Witcombe et al., 1988). Poor seed delivery systems remain a major constraint in many parts of Africa (Tripp, 2001).

Plants

**Domestication, intensive selection and conventional breeding have had major impacts on yield and production of staple food crops, horticultural crops and timber trees.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | A | +2 to +5 | G | Widespread applicability |

Yield per unit area of the world's staple food crops, especially cereals (rice, wheat and maize) have increased over the last 50 years (Figure 3.2a), as a result of publicly and privately funded research on genetic selection and conventional breeding (Simmonds, 1976; Snape, 2004; Swaminathan, 2006). Increased wheat and barley yield in the UK (Silvey 1986; 1994), and maize yield in the USA (Duvick and Cassman, 1999; Tollenaur and Wu, 1999), e,g., is attributed equally to advances in breeding and to improved crop and soil management. Gains in productivity between 1965 and 1995 were about 2% per annum for maize, wheat and rice (Evenson and Gollin, 2003a; Pingali and Heisey, 1999), though rates have declined in the last decade. Similarly, productivity measured as total factor productivity (TFP) also increased in rice, wheat and maize (Evenson, 2003a; Pingali and Heisey, 1999). The impact of crop improvement on non-cereals has been less well documented as these crops are often far more diverse, occupy smaller areas globally and are not traded as commodities. For example, in total legumes occupy 70.1 m ha globally, but there a greater diversity of legume species is used with clear regional preferences and adaptation (e.g. cowpeas,*Vigna unguiculata*, in West Africa; pigeon pea, *Cajanus cajan*, and mung bean, *Vigna radiata*, in India). Nonetheless, plant breeding has increased yields in many protein crops (Evenson and Gollin, 2003b).

**Much of the increase in crop yield and productivity can be attributed to breeding and dissemination of Modern Varieties (MV) allied to improved crop management.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | A | -2 to +5 | G | Widespread applicability |

A number of studies (Evenson and Gollin, 2003ab; Pingali and Heisey, 1999; Raitzer, 2003; Lantican et al., 2005; Heisey et al., 2002; Hossain et al., 2003) have quantified the large impact (particularly in industrialized countries and Asia) of crop genetic improvement on productivity (Figure 3.2). Much of this impact can be attributed to IARC genetic research programs, both direct (i.e. finished varieties) and indirect (i.e. parents of NARS varieties, germplasm conservation). Benefit-cost ratios for genetic research are substantial: between 2 (significantly demonstrated and empirically attributed) and 17 (plausible, extrapolated to 2011) (Raitzer, 2003). Two innovations – rice and wheat MVs rice (47% and 31% of benefits, respectively) account for most of the impact. Benefits can also be demonstrated for many other crops. For example, an analysis of the CIAT bean (*Phaseolus vulgaris*) breeding program (Johnson et al., 2003) showed that 49% of the area under beans could be attributed to the CIAT breeding program, raising yield by 210 kg $ha^{-1}$ on average and resulting in added production value of US $177 m. For Africa, where the breeding program started later, about 15% of the area is under cvs that can be attributed to CIAT, with an added value of US $26 m. The estimated internal rate of return was between 18 and 33%, with more rapid positive returns in Africa, which built upon earlier work in LAC.

**Although the adoption of MVs is widespread, many MVs may be old and farmers are therefore not benefiting from the latest MV with pest/disease resistant and superior yield.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | C | -1 to –3 | G | High and low potential systems |

Although new and potentially better MVs have been released in many countries, these have not been grown by farmers, more often than not due to the inefficiency of the varietal release and seed multiplication system (Witcombe et al. 1988) rather than poor suitability. For example, in high potential areas of the Punjab the most commonly grown wheat and rice MVs were 8-12 and 11-15 years old (Witcombe, 1999; Witcombe et al., 2001). The age of an MV in use may also vary with environment, with lower rates of turnover in more marginal areas where suitable MVs have not been released (Smale et al., 1998; Witcombe et al., 2001). Assuming that genetic gains in potential yield achieved each year are on the order of 1 to 2% (e.g. Figure 3.5), then farmers may be losing 16 to 30% of potential yield; these losses will be even higher where MVs have superior disease or pest resistance.

**[Insert Figure 3.5]**

**Gains in productivity from MVs have been greatest in high potential areas, particularly irrigated rice and wheat, but benefits have also occurred is less favorable areas.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | B | +1 to +2 | G | Low potential environments |

Yield gains of wheat on farmers' fields in more marginal environments were between 2-3% between 1979 and 1996 (Byerlee and Moya, 1993; Lantican et al., 2005), compared with increases with irrigation of about 1% per annum between 1965 and 1995 (Lantican et al., 2005). These more recent gains stem from breeding efforts based on greater understanding of marginal environments, such as those with acid soils or heat/drought stress (Reynolds and Borlaug, 2006). In maize, about 50% of the increase in yield attributed to genetic gain is due to improvements in stress tolerance (Tollenaur and Wu, 1999), which has contributed to maize expansion in more marginal environments.

**Crop improvement has reduced genetic diversity, but current breeding strategies are tackling this problem.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | -2 to +2 | G | Widespread |

In Asia, MVs account for >75% area for wheat and rice and village level studies in Nepal have shown incidences of a single wheat MV, CH45, occupying 96% of the area (Evenson and Gollin 2003b; Witcombe et al., 2001). Elsewhere, notably in Africa and CWANA, MVs occupy smaller proportions and many more TVs can be found (Evenson and Gollin, 2003b). The loss of genetic diversity due to the widespread adoption of MVs has resulted in negative environmental impacts

(Evenson and Gollin 2003ab): reducing the availability of genes for future crop improvement, creating the possibility for inbreeding depression (with negative impacts on production), reducing species ability to adapt to change (eg. climate change) and evolving resistance to new pest and disease outbreaks. However, this is disputed (Maredia and Pingali, 2001). Genetic diversity can vary both temporally and spatially, and both have to be taken into account in assessing impacts on diversity. The rapid replacement of old varieties with newer ones has increased the temporal diversity in Mexico and Pakistan, especially when current breeding programs increasingly use more genetically diverse traditional varieties in their parentage (Smale, 1997; Smale *et al*., 1998; Hartell *et al*., 1998). This has been confirmed by a recent molecular study of genetic diversity in wheat (Reif *et al.*, 2005). However, molecular analysis of MVs by ages, areas and genealogies, has shown clearly that diversity in spring wheat in developing countries has not decreased since 1965 (Smale et al., 2002).

**Genetic yield potential is not increasing.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | C | -3 to +1 | G | Widespread |

Plant breeding in developed and less developed countries has to date been successful at delivering new, higher yielding varieties, largely through better adaptation, greater partitioning of biomass to seed (i.e. harvest index; Austin et al., 1980; Sayre et al., 1997) and disease resistance. However, under conditions where pests are efficiently controlled and there are no limitations to the supply of water and nutrients, there is evidence (Figure 3.5) that the yield potential of the most productive rice, wheat, and maize cultivars has not markedly increased since the Green Revolution (Peng et al., 1999; Sayre et al., 2006; Duvick and Cassman, 1999). Even in the UK, where the benefits of plant breeding have been well documented (Silvey, 1986; 1994), national wheat yields are only increasing slowly (Sylester-Bradley et al., 2005); although in any given year yields of the best varieties in National Recommended List trials show average gains >2% per year above the most recently released varieties (Austin, 1999; http://www.hgca.com/content.template/23/0/Varieties/Varieties/Varieties%20Home%20Page.mspx) It is clear that when harvest indices in some annual grasses and legumes, are approach their theoretical maximum, selection for increased total crop biomass and/or the exploitation of hybrid vigor will be important. Hybrid rice, which yields about 15% more than conventionally bred rice, is already grown on some 15 m ha in China (about half the total area in rice) (Longping, 2004), and hybrid sorghum shows similar promise.

**Gains in yield per unit area per year are expected to remain lower than historical yields.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | A | -2 to 0 | G | Widespread |

Conceptually, crop improvement goes through stages of domestication to produce Traditional Varieties (TVs), and then TVs are replaced by a succession of MVs (Otsuka and Yamano, 2005). In wheat, rice and maize gains were initially much higher (35-65%) when MV replaced traditional varieties (Otsuka and Yamano, 2005) Subsequent gains when MV2 replace MV1 have been lower (10-30%). This reduction in gain is to be expected, as many TVs were not necessarily well adapted, especially to changing climates, and yield may have been constrained by susceptibility to major pest and diseases, or non-biotic constraints such as lodging. Furthermore, once major constraints are tackled, most breeding efforts go into maintaining resistance and enhancing quality, and not simply increasing yield potential (Baenziger et al., 2006; Legg, 2005). Constraints due to soil fertility and structure, and diseases and pests from continuous cultivation limit increases in yield potential (see below; Cassman et al., 2003). Nonetheless, further small gains are expected, through continued genetic gain and a better understanding and breeding for specific target environments (Reynolds and Borlaug, 2006). In developing countries and low yield potential environments the benefits of breeding for specific environments will be further enhanced with the adoption of more localized and/or participatory breeding, i.e. with the exploitation of G × E or local adaptation.

**In several intensive production environments, cereal yields are not increasing.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, D | A | -2 to -4 | G | Intensive production systems |

In several of the most important regions for irrigated rice production (e.g. areas of China, Japan, Korea) there is strong evidence of persistent yield stagnation at approximately 80% of the theoretical productivity levels predicted by simulation models (Cassman et al., 2003). This type of stalled exploitation of potential production is primarily caused by economic factors since the rigorous management practices required for yield maximization are not cost effective (Cassman et al., 2003; Pingali and Heisey, 1999). Rice yield stagnation has also been observed in areas like Central Java and the Indian Punjab at levels significantly below 80% of the theoretical productivity. In long-term cropping system experiments (LTE) with the highest-yielding rice varieties under optimal pest and nutrient management, rice yield potential declined at several locations. Subsequent evidence from a larger set of LTEs suggested that this phenomenon was not widespread, but that rice yield potential was essentially stagnant in most regions despite putative innovations in management and plant genetic resources (Dawe et al., 2000). For irrigated production systems in the maize belt of the United States, yields achieved by the most productive farmers have not increased since the mid-1980s (Duvick and Cassman, 1999). For spring wheat producers in Mexico’s Yaqui Valley, only nominal increases in yield have been observed since the late 1970s.

**In many regions the production potential for the staple cereal crops has not been exhausted.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N L, E, D | B | -2 to +2 | R | Not clear |

In contrast to concerns about limited future opportunities for yield improvement in cereals, there are some examples of yield increases. For example, coordinated efforts to improve management practices and profitability of Australian rice systems increased productivity from 6.8 tonnes $ha^{-1}$ in the late 1980s to 8.4 tonnes $ha^{-1}$ by the late 1990s (Ferrero and Nguyen, 2004). Farm-level maize yields in the United States are typically less than half of the climate-adjusted potential yield (Dobermann and Cassman, 2002). At the state level in India, an analysis (Bruinsma, 2003) suggests that rice productivity could be increased by 1.5 tonnes $ha^{-1}$ (ca. 50%) without exceeding the 80% criteria commonly used to establish the economically-exploitable component of the biophysical yield potential (Bruinsma, 2003).

**In developing countries the productivity of many small-scale farming systems is often constrained by limited access to inputs and modern varieties (MVs) and poor management practices.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, D | A | -2 to -5 | G | Small-scale farms in developing countries |

In upland rice systems in Laos, the importance of the adoption of improved varieties and N fertilization has been demonstrated (Saito et al., 2006). By substituting MVs for traditional landraces, rice yields doubled to 3.1 tonnes $ha^{-1}$ with a moderate dose of nitrogen fertilizer further improving yield by 1 tonne $ha^{-1}$. Among farmers in Nepal, modern crop management practices (e.g. timely establishment, precision planting, two weedings) together with site-specific nutrient management boost rice productivity by 2 tonnes $ha^{-1}$ over typical farmer practices (Regmi and Ladha, 2005). In West Africa, rural surveys show that most farmers have limited knowledge of soil fertility management and of optimal establishment practices for rice (Wopereis et al., 1999). In these areas, nitrogen deficiency, inadequate weeding, and late planting are commonly associated with low cereal productivity (Becker and Johnson, 1999). Poor knowledge of efficient practices for maintaining soil fertility has also been identified as an important component of the low yields achieved by Bangladeshi rice farmers (Gaunt et al., 2003).

**Barriers to clonal forestry and agroforestry have been overcome by the development of robust vegetative propagation techniques, which are applicable to a wide range of tree species.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | B | +3 to +5 | G | Widespread applicability |

Techniques of vegetative propagation have existed for thousands of years (Hartmann et al., 1997), but the factors affecting rooting capacity seem to vary between species and even clones (Leakey, 1985; Mudge and Brennan, 1999). However, detailed studies of the many morphological and physiological factors affecting five stages of the rooting process in stem cuttings (Leakey, 2004) have resulted in some principles, which have wide applicability (Dick and Dewar, 1992) and explain some of the apparently contradictory published information (Leakey, 2004). Robust low-technology vegetative propagation techniques are now being implemented within participatory village-level development of cultivars of indigenous fruit/nut tree species to diversify cocoa farming systems in West Africa (Leakey et al., 2003).

**Participatory domestication techniques are using low-tech approaches to cloning to develop cultivars of new tree crops for agroforestry.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | +1 to +3 | M-L | Wide applicability |

Simple, inexpensive and low-tech methods for the rooting of stem cuttings have been developed for use by resource poor farmers in remote village nurseries (Leakey et al., 1990). These robust and appropriate techniques are based on a greatly increased understanding of the factors affecting successful vegetative propagation (Leakey, 2004). The identification of selection criteria is being based on the quantitative characterization of many fruit and nut traits (Atangana et al., 2001, 2002; Anegbeh et al., 2003, 2004; Waruhiu et al., 2004; Leakey et al., 2005bc; Leakey, 2005b). Using participatory approaches (Leakey et al., 2003), the implementation of these techniques is being successfully achieved by small-scale farmers from 40 communities (Tchoundjeu et al., 2006).

**Clonal approaches to the genetic improvement of timber tree species result in large improvements in yield and quality traits.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | A | +2 to +5 | G | Widespread applicability |

For example in timber species, clones of *E. urophylla* x *E. grandis* hybrid in Congo were planted in monoclonal blocks of 20-50 ha at a density of 800 stems ha$^{-1}$ and resulted in mean annual increments averaging 35 m$^{3}$ ha$^{-1}$ a$^{-1}$, compared with 20-25 m$^{3}$ ha$^{-1}$ yr$^{-1}$ from selected provenances, and about 12 m$^{3}$ ha$^{-1}$ a$^{-1}$ from unselected seedlots (Delwaulle, 1983). In Brazil, mean annual increments between 45-75 m$^{3}$ ha$^{-1}$ yr$^{-1}$ and up to 90m$^{3}$ ha$^{-1}$ yr$^{-1}$ have been recorded (Campinhos, 1999). Clonal approaches require (Leakey, 1987; Ahuja and Libby 1993ab) genetic diversity (Leakey, 1991), wise deployment (Foster and Bertolucci, 1994) and appropriate silviculture (Evans and Turnbull, 2004; Lawson, 1994) to maximize gains, minimize pest and pathogen risks and maintain species diversity in the soil microflora (Mason and Wilson, 1994), soil invertebrates (Bignell et al., 2005) and insect populations (Watt et al., 1997, 2002; Stork et al., 2003).

**Increased private sector involvement in timber plantations has recently been more inclusive of social and environmental goals.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | -1 to +3 | G | Wide applicability |

In the past, the cultivation of planted timber trees has mostly been implemented by national forestry agencies, often with inadequate attention to establishment techniques. In the last 20-30 years there has been increasing private sector investment, much of which has been multinational, and often in partnership with local companies or government agencies (Garforth and Mayers, 2005). These companies have focused on a few fast-growing species, especially for pulp and paper industries, often grown as exotic species outside their natural range. In these plantations genetic improvement has typically been achieved by provenance selection and clonal technologies. Increasingly, such plantations are being designed as 'mosaic' estates with a view to greater synergies with both local agricultural conditions and areas protected for biodiversity (IIED, 1996) and as joint ventures with communities to provide non-fiber needs in addition to wood (Mayers and Vermeulen, 2002).

Livestock and fish

**Domestication and the use of conventional livestock breeding techniques have had a major impact on the yield and composition of livestock products.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L | A | 0 to +4 | G | Widespread but, mostly in developed countries |

There has been widespread use of breed substitution in industrialized countries and some developing countries, often leading to the predominance of a few very specialized breeds, and often pursuing quite narrow selection goals. Organized within-breed selection has been practiced much less widely in many developing countries, partly because of the lack of infrastructure, such as national or regional performance recording and genetic evaluation schemes. Genetic improvement – breed substitution, crossbreeding and within-breed selection – has made an important contribution to meeting the growing global demand for livestock products. Selection among breeds or crosses is a one off, non-recurrent process: the best breed or breed cross can be chosen, but further improvement can be made only by selection within the populations (Simm *et al.,* 2004). Crossbreeding is widespread in commercial production, exploiting complementarity of different breeds or strains, and heterosis or hybrid vigor (Simm, 1998). Trait selection within breeds of farm livestock typically produces annual genetic changes in the range 1-3% of the mean (Smith, 1984). Higher rates of change occur for traits with greater genetic variability, in traits that are not age- or sex-limited, and in species with a high reproductive rate, like pigs and poultry (McKay *et al*., 2000; Merks, 2000), fish and even dairy cattle (Simm, 1998). These rates of gain have been achieved in practice partly because of the existence of breeding companies in these sectors. Typically, rates of genetic change achieved in national beef cattle and sheep populations have been substantially lower than those theoretically possible, though they have been achieved in individual breeding schemes. The dispersed nature of ruminant breeding in most countries has made sector-wide improvement more challenging.

**In most species, rates of change achieved in practice through breeding have increased over the last few decades in developed countries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L | A | 0 to +4 | G | Developed countries |

The greatest gains in productivity as a result of genetic improvement have been made in poultry, pigs and, to a lesser extent, dairy cattle. Greater success through breeding programs in developed countries has been the result of: better statistical methods for estimating the genetic merit (breeding value) of animals, especially best linear unbiased prediction methods; the wider use of reproductive technologies, especially artificial insemination; improved techniques for measuring performance (e.g. ultrasonic scanning to assess carcass composition *in vivo*); and more focused selection on objective rather than subjective traits, such as milk yield rather than type. Developments in the statistical, reproductive and molecular genetic technologies available have the potential to increase rates of change further (Simm et al., 2004). In recent years there has been a growing trend in developed countries for breeding programs to focus more on product quality or other attributes, rather than yield alone. There is also growing interest in breeding goals that meet wider public needs, such as increasing animal welfare or reducing environmental impact.

**Gains in productivity have been variable if breeds are not matched to the environment**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, D | B | 0 to +3 | G | Developing countries |

The gains in productivity per animal have been greatest in developed countries, and in the more ‘industrialized’ production systems in some developing or ‘transition’ countries. The enormous opportunities to increase productivity through wider adoption of appropriate techniques and breeding goals in developing countries are not always achieved. Breed substitution and crossing have both given rapid improvements, but it is essential that new breeds or crosses are appropriate for the environment and resources available over the entire production life cycle. Failure to do this has resulted in herds that have succumbed to diseases or to nutritional deprivation to which local breeds were tolerant, e.g. the introduction of high performing European dairy breeds into the tropics that had lower survival than pure Zebu animals and their crosses. The reproductive rate of the pure European breeds is often too low to maintain herd sizes (de Vaccaro, 1990). It is also important that valuable indigenous Farm Animal Genetic Resources (FanGR) are protected.

**Large scale livestock production can lead to environmental problems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, S | B | -2 to +3 | G | Urban centres in developing countries |

Recently, livestock production has increased rapidly, particularly in developing countries where most of the increased production comes from industrial farms clustered around major urban centers (FAO, 2005c). Such large concentration of animals and animal wastes close to dense human population often causes considerable pollution problems with possible negative effects on human health. Large industrial farms produce more waste than can be recycled as fertilizer and absorbed on nearby land. When intensive livestock operations are crowded together, pollution can threaten the quality of the soil, water, air, biodiversity, and ultimately public health (FAO, 2005c). In less intensive mixed farming systems, animal wastes are recycled as fertilizer by farmers who have direct knowledge and control of their value and environmental impact. However in industrial production, there is a longer cycle in which large quantities of wastes accumulate.

**Livestock production is a major contributor of emissions of polluting gases.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, S | B | -2 to +3 | G | All livestock |

Livestock production is a major contributor of emissions of polluting gases, including nitrous oxide, a greenhouse gas whose warming potential is 296 times that of carbon dioxide. Livestock contributes 18% of the total global warming effect, larger even than the transportation worldwide (Steinfeld et al., 2006). The share of livestock production in human-induced emissions of gases is 37% of total methane, 65% of nitrous oxide, 9% of total carbon dioxide emissions and 68% of ammonia emissions (Steinfeld et al., 2006). This atmospheric pollution is in addition to the water pollution caused by large-scale industrial livestock systems.

**Aquaculture has made an important contribution to poverty alleviation and food security in many developing countries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | B | +1 to +3 | G | Developing countries |

Aquaculture, including culture-based fisheries, has been the world's fastest growing food-producing sector for nearly 20 years (FAO, 2002c; Delgado et al., 2003a*;* Bene and Heck, 2005a; World Bank, 2007b). In 1999, 42.8 million mt of aquatic products (including plants) valued at US $53.5 billion were produced, and more than 300 species of aquatic organisms are today farmed globally. Approximately 90% of the total aquaculture production is produced in developing countries, with a high proportion of this produced by small-scale producers, particularly in low income food deficit countries (Zeller et al., 2007). While export-oriented, industrial and commercial aquaculture practices bring in needed foreign exchange, revenue and employment, more extensive and integrated forms of aquaculture make a significant grass-roots contribution to improving livelihoods among the poorer sectors of society and also promote efficient resource use and environmental conservation (FAO, 2002c). The potential of aquaculture has not yet been fully realized in all countries (Bene and Heck, 2005ab; World Bank, 2007b).

**Globally, *per capita* fish consumption increased by 43% from 11 kg to 16kg between 1970 and 2000**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H | B | 0 to +2 | G | Asia particularly |

In developing countries, fish have played an important role in doubling animal protein consumption per capita over the last 30 years – from 6.3 to 13.8 kg between 1970 and 2000. In the developed world, fish consumption increased by less than one-half during the same period. Urbanization and income and population growth are the most significant factors that increasing fish consumption in developing countries, particularly in Asia (Dey et al., 2004).

**The recent increase in aquaculture production is primarily due to advances in induced breeding or artificial propagation techniques (hypophysation).**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, S | B | -2 to +3 | G | Freshwater carp farming |

Induced breeding and hypophysation have particularly occurred in the carp polycultures and in freshwater fish farming in rice fields, seasonal ditches, canals and perennial pond**s.** However, in Bangladesh, hatchery-produced stock (mainly carps) have shown adverse effects such as reduced growth and reproductive performance, increased morphological deformities, and disease and mortalities. These effects are probably due to genetic deterioration in the hatchery stocks resulting from poor fish brood stock management, inbreeding depression, and poor hatchery operation (Hussain and Mazid, 2004).

**Aquaculture has had positive and negative effects on the environment.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, S | B | -2 to +3 | G | Coastal ecosystems |

There have been negative and positive impacts of aquaculture on the environment, depending on the intensification of the production systems. An incremental farmer participatory approach to the development of sustainable aquaculture in integrated farming systems in Malawi (Brummett, 1999) found that integrated farming systems are more efficient at converting feed into fish and produce fewer negative environmental impacts. The widespread adoption of integrated aquaculture could potentially improve local environments by reducing soil erosion and increasing tree cover (Lightfoot and Noble, 1993; Lightfoot and Pullin, 1995; Brummett, 1999). Negative environmental effects resulting from the aquaculture industry include threats to wild fish stocks (Naylor et al., 2000); destruction of mangrove forests and coastal wetlands for construction of aquaculture facilities; use of wild-caught rather than hatchery-reared finfish or shellfish fry to stock captive operations (often leading to high numbers of discarded by-catch of other species); heavy fishing pressure on small ocean fish for use as fish meal (depleting food for wild fish); transport of fish diseases into new waters; and non-native fish that may hybridize or compete with native wild fish. Improvements in management can help to reduce the environmental damage (Lebel et al., 2002), but only to a minor extent. However, economic impacts are site-specific. Intensive aquaculture has also had important effects on the landscape, e.g., in Thailand 50-65% of the mangroves have been replaced by shrimp ponds (Barbier and Cox, 2002).

*3.2.1.2.2 Breeding for abiotic and biotic stress tolerance*

Crops and plants, especially in marginal environments, are subjected to a wide and complex range of biotic (pests, weeds) and abiotic (extremes of both soil moisture and air/soil temperature, poor soils) stresses. Abiotic stresses, especially drought stress (water and heat) have proved more intractable.

**Progress in breeding for marginal environments has been slow.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +1 | R | Widespread aplicability |

Progress in breeding for environments prone to abiotic stresses has been slow, often because the growing environment was not characterized or understood (Reynolds and Borlaug, 2006), too many putative stress tolerant traits proved worthless (Richards, 2006), and because the complex nature of environment-by-gene interactions was not recognized and yield under stress has a low heritability (Baenziger et al., 2006). Drought, for example, is not easily quantifiable (or repeatable) in physical terms and is the result of a complex interaction between plant roots and shoots, and soil and aerial environments (Passioura, 1986). Furthermore, much effort was expended on traits that contributed to survival rather than productivity.

**Although yield and drought tolerance are complex traits with low heritability, it has been possible to make progress through conventional breeding and testing methods.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | D | 0 to +1 | R | CWANA, SSA |

Breeding for marginal and stressed environments has not been easy, especially where wide-adaptation was also important. However, breeding programs that make full use of locally-adapted germplasm and TVs (Ceccarelli et al. 1987), and select in the target environments (Ceccarelli and Grando, 1991; Banziger et al., 2006) have been successful. For example, in Zimbabwe, where soil fertility is low and drought stress common, the careful selection of test environments (phenotyping) and selection indices can increase maize yields across the country and regionally (Banziger et al., 2006). Equal weight to three selection environments (irrigated, drought stress, N-stress), the use of moderately severe stress environments, and the use of secondary traits with higher heritabilities improved selection under stress. In multilocation trials, lines selected using this method out-yielded other varieties at all yield levels, but more so in more marginal environments. This would seem to be a successful blue print for conventional breeding for stress environments.

**Although drought tolerance is a complex trait, progress has been made with other aspects of abiotic stress tolerance.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +2 | G | Many crops |

Yield is the integration of many processes over the life of a crop,and as such it is unsurprising that heritabilities are low and progress slow. In contrast, the effects of some abiotic stresses are associated with very specific stages of the life cycle (particularly flowering and seed-set) or are associated with very specific mechanisms, and these appear to be more amenable to selection. Progress has been made in breeding for tolerance to a number of stresses, including extremes of temperature (hot and cold), salt and flooding/submergence, and nutrient deficiency. For example, tolerance to extremes of temperature, which are important constraints in many crop species at and during reproductive development (i.e. in the flowering period), have been identified (Hall, 1992; Craufurd et al., 2003; Prasad et al., 2006) and in some cases genes identified and heat tolerant varieties bred (Hall, 1992). These particular responses will be increasingly valuable as climate changes.

**Biological control has been successfully adopted in pest control programs to minimize the use of pesticides and reduce environmental and human health risks.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | B | +1 to +3 | M-L | Wide applicability |

Ten percent of the world's cropped area involves classical biological control. The three major approaches to biological control are: importation, augmentation and conservation of natural enemies (DeBach, 1964). Biological control through importation can be used in all cropping systems in developing and industrialized countries (Gurr and Wratten, 2000; van Lenteren, 2006) and has been applied most successfully against exotic invaders. Successful control is most often totally compatible with crop breeding (DeBach, 1964; Thomas and Waage, 1996), and provides economic returns to African farmers of the same magnitude as breeding programs (Neuenschwander, 2004; Raitzer, 2003). In augmentation forms of biological control, natural enemies (predators, parasitoids and pathogens) are mass produced and then released in the field, e.g., the parasitic wasp *Trichogramma* is used on more than 15 million ha of agricultural crops and forests in many countries (Li, 1994; van Lenteren and Bueno, 2003), as well as in protected cropping (Parrella et al., 1999; van Lenteren, 2000). A wide range of microbial insect pathogens are now in production and in use in OECD and developing countries (Moscardi, 1999; Copping, 2004). For example, the fungus *Metarhizium anisopliae* var *acridum* 'Green Muscle' ® is used to control Desert Locust (*Schistocerca gregaria*) in Africa (Lomer et al., 2001). Since agents vary in advantages and disadvantages, they must be carefully selected for compatibility with different cropping systems. However agents are playing an increasing role in IPM (Copping and Menn, 2000). In conservation biological control, the effectiveness of natural enemies is increased through cultural practices (DeBach and Rosen, 1991; Landis et al., 2000) that enhance the efficiency of the exotic or indigenous natural enemies (predators, parasitoids, pathogens).

**The economic benefits of biological control can be substantial.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | +5 | G | Wide applicability |

Cultures of the predatory mite, *Metaseiulus occidentalis*, used in California almond orchards saved growers \$59 to \$109 $ha^{-1}$ $yr^{-1}$ in reduced pesticide use and yield loss (Hoy, 1992). The fight against the cassava mealy bug in Africa has had even greater economic benefits (Neuenschwander, 2004). IITA and CIAT found a natural enemy of the mealy bug in Brazil in the area of origin of the cassava crop. Subsequently, dissemination of this natural enemy in Africa saved million of tonnes of cassava per year and brought total benefits of US \$billions (Zeddies et al., 2001; Raitzer, 2003). Similar benefits for small-scale farmers have accrued from other programs on different crops and against different invaders across Africa (Neuenschwander, 2004).

**Weed competition is a significant barrier to yield and profitability in most agroecosystems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, D | A | -2 to -5 | G | Widespread |

In many developing countries, hand weeding remains the prevailing practice for weed control. On small-scale farms, more than 50% of pre-harvest labor is is devoted to weed management, including land preparation and in-crop weed control (Ellis-Jones et al., 1993; Akobundu, 1996). Despite these labor investments crop losses to weed competition are nearly universally identified as major production constraints, typically causing yield reductions of 25% in small-scale agriculture (Parker and Fryer, 1975). Delayed weeding is a common problem caused by labor shortages, and reduced labor productivity resulting from diseases such malaria and HIV/AIDS. Hence, cost-effective low-labor control methods have become increasingly important. In Bangladesh with current methods, one-third of the farmers lose at least 0.5 tonne $ha^{-1}$ grain to weeds in each of the three lowland rice seasons (Ahmed et al., 2001; Mazid et al., 2001). Even in areas that employ herbicides, yield losses are substantial; in the early 1990s annual losses of US \$4 billion were caused by weed competition in the US. For staple cereal and legume crops like maize, sorghum, pearl millet, upland rice in semi-arid areas of Africa, the parasitic witchweeds (*Striga* species) can cause yield losses ranging from 15 to 100% (Boukar et al., 2004). *Striga* infestation is associated with continuous cultivation and limited returns of plant nutrients to the soil, i.e., conditions typical of small-scale resource poor farms (Riches, et al, 2005).

**Intensive herbicide use has contributed to improved weed management but there are concerns about sustainable use and environmental quality.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, D | A, B | -2 to +5 | G | Widespread |

Globally, approximately 1 billion kg of herbicide active ingredients are applied annually in agricultural systems (Aspelin and Grube, 1999). The benefits of judicious herbicide use are broadly recognized. In addition to tillage, prophylactic application of herbicide is the method of choice for managing weeds in industrialized countries and is also widely employed in highly productive agricultural regions in developing countries like Punjab and Haryana States in India. Herbicide use is also becoming more common in small-scale rice/wheat systems in Eastern India and in rice in countries such as Vietnam and Bangladesh where the price of labor is rising faster than crop values (Auld and Menz, 1997; Riches et al*.,* 2005). Substitution of labor by herbicides in Bangladesh reduces weeding costs by 40-50% (Ahmed et al*.,* 2001). Herbicides sold in small quantities are accessible to poor farmers who realize their value; rice herbicide sales have been increasing at 40-50% per year since 2002 (Riches et al., 2005). However, herbicide resistance (currently documented in 313 weed biotypes: www.WeedScience.org) and environmental contamination are growing problems. Traces of Atrazine and other potential carcinogens are routinely documented in ground and surface water resources in industrialized countries (USGS, 1999), and on a global scale the quantity of active ingredient applied as herbicide and the energy required for manufacturing and field application is larger than all other pesticides combined (FAO, 2000a). In the developing country context, acute poisoning of agricultural workers from improper handling of herbicides also poses a significant public health risk that is linked to factors such as insufficient access to high-quality protective gear, poor product labeling, and low worker literacy rates (Repetto and Baliga, 1996). However, many of the newer classes of herbicide chemistry entering the market have much more favorable environmental profiles than commonly used insecticides and can be used at very low doses. Registration of new classes of herbicides has slowed (Appleby, 2005), which places a heightened imperative on maintaining the long-term efficacy of existing herbicides. There are also concerns for the sustainable use of compounds like glyphosate that are applied in conjunction with herbicide resistance crops (HRCs). Farmers using HRCs tend to extensively rely on a single herbicide at the expense of all other weed control measures, thereby decreasing long-term efficacy by increasing the odds of evolved herbicide resistance. However these worries are less of an issue in smaller-scale systems where HRCs have not been previously used and seed systems make their widespread use less likely in the near future. Herbicides also have potential for reducing the cost of management of some important perennial and parasitic weed problems. Glyphosate is showing promise with farmers in Nigeria to reduce competition from the perennial grass *Imperata cylindrica* (Chikoye et al., 2002) and can reduce tillage inputs for management of other intractable perennial species, while in East Africa imazapyr herbicide tolerant maize has been introduced to combat *Striga* (Kanampiu et al., 2003)

**Non-chemical control strategies can limit crop damage from weed competition.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, D | B, D | +1 to +3 | G | Widespread |

From a plant protection standpoint, weed management attempts to reduce densities of emerging weeds, limit crop yield losses from established weeds, and to promote the dominance of comparatively less damaging and difficult to control species in the weed community. The first line of defense against weeds is a vigorous crop; basic crop management and cultural practices are important to maximize crop competitiveness and thereby reduce weed competition. Cultivars that are bred for competitive ability (Gibson *et al*., 2003), diverse crop rotations that provide a variety of selection and mortality factors (Westerman et al., 2005), and simple management changes such as higher seeding rates, spatially-uniform crop establishment (Olsen et al., 2005), and banded fertilizer placement (Blackshaw et al., 2004) can reduce crop losses from uncontrolled weeds and, in some cases, reduce herbicide dependence. In conventional production settings, few of these options have been explicitly adopted by farmers. Cultural practice innovations for weed control work best if they are compatible and efficient complements to existing agronomic practices, hence it is important to note the needs and constraints of farmers when developing new options for weed management (Norris, 1992). Hence participatory approaches are commonly used to ensure that practices are appropriate to farmer needs (Riches et al., 2005; Franke et al., 2006).

**Parasitic weeds are major constraints to several crops but a combination of host-plant resistance and management can control them.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | +2 to +5 | G | Farmers in Africa, Asia and Mediterranean |

Parasitic weeds such as *Striga* spp. and *Alectra vogelii* are major production constraints to several important crops, especially maize, sorghum and cowpea in SSA. Sources of resistance to *S. gesneroides* and *A. vogellii* were identified by traditional methods and the genes conferring resistance to and *A. vogellii* were subsequently identified using Amplified Fragment Length Polymorphism markers (Boukar et al., 2004) and successfully deployed in cowpea across W. Africa (Singh et al., 2006). Host-plant resistance to *S. asiatica* and *S. hermonthica* is now being deployed widely in new sorghum cultivars in East Africa but has been harder to find in maize. Inbred maize lines carrying tolerance to *Striga* have been developed and tolerance is quantitatively inherited (Gethi and Smith, 2004). However, the most successful strategy for controlling *Striga* in maize in West Africa is the use of tolerant cultivars used in rotation, and trap-cropping, using legumes, especially soybean, to germinate *Striga* seeds to reduce the seedbank

(Franke et al., 2006). As *Striga* infestation is closely associated with low soil fertility, nutrient management, especially addition of nitrogen, can greatly increase yields of susceptible crops on infested fields. Farmers are now adopting green manures in legume/cereal rotations in Tanzania as a low-cost approach to reversing the yield decline of maize and upland rice (Riches et al., 2005). The inter-planting of maize with *Desmodium* spp. within the "push-pull" system (Khan et al., 2006; Gatsby Charitable Foundation, 2005) is a promising approach to *Striga* suppression in East Africa. The broomrapes, *Orobanche* spp. are a major problem on sunflower, faba bean, pea, tomato and other vegetable crops in the Mediterranean basin, central and eastern Europe and the Middle East. Sources of resistance to broomrapes (*Orobanche* species) in a number of crops and the associated genes have been identified and mapped (Rubiales et al., 2006).

**The increasing rate of naturalization and spread (i.e., invasions) of alien species introduced both deliberately and accidentally poses an increasing global threat to native biodiversity and to production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | A | -1 to -5 | R | Widespread occurrence |

Alien species are introduced deliberately either as new crops/livestock or as biocontrol agents; or by mistake as contamination of seed supplies or exported goods. Natural dispersal mechanisms account for only a small proportion of newly introduced species. This environmental problem has been ranked second only to habitat loss (Vitousek et al., 1996) and has totally changed the ecology of some areas (eg. Hawaii). Negative economic and environmental impacts include crop failures, altered functioning of natural and manmade ecosystems, and species extinctions (Ewel et al., 1999). For example, in just one year the impact of the introduced golden apple snail (Pomacea canaliculata) on rice production cost the Philippine economy an estimated US $28-45 million, or approximately 40% of the Philippines' annual expenditure on rice imports (Naylor, 1996).

**The late 20$^{th}$ century saw the emergence of highly virulent forms of wheat stem rust and cassava mosaic disease that are serious threats to food security.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H ,L, S | A | -5 to -4 | G | Most agricultural systems |

The Ug99 race of *Puccinia graminis*, first discovered in East Africa, is virulent on most major resistance genes in wheat, which have provided effective worldwide protection against epidemic losses from wheat rust over the past 40 years (CIMMYT, 2005; Pretorius et al., 2002; Wanyera et al., 2006). Yield loss from Ug99 typically ranges from 40 to 80%, with some instances of complete crop failure (CIMMYT, 2005). The capacity for long-range wind dissemination of viable spores on the jet stream, the ubiquity of susceptible host germplasm, and the epidemic nature of wheat stem rust pose a significant threat to wheat producing regions of Africa and Asia, and possibly beyond. The Ug99 race recently crossed the Red Sea to Yemen, and is projected to follow a similar trajectory as the Yr-9-virulent wheat stripe rust, making its arrival in Central and South Asia possible within the next five or more years (CIMMYT, 2005; Marris, 2007).

**Cassava mosaic virus (CMV) is a threat to a staple crop vital for food security.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S | A | -4 to -3 | R, G | Especially in Africa |

In the late 1980's, CMV underwent recombinant hybridization of two less virulent virus types resulting in a severe and rapidly spreading form of cassava mosaic disease (Legg and Fauquet, 2004). CMD has expanded, via whitefly transmission and movement of infected planting stock, throughout East and Central Africa causing regional crop failure and famine (Anderson et al., 2004; Legg and Fauquet, 2004; Mansoor et al., 2003). CMD represents the first instance of a synergy between viruses belonging to the same family, which could confront agriculture with the future emergence of new and highly virulent geminivirus diseases (Legg and Fauquet, 2004). Cassava is important to future food security in Africa since it is hardy under normally low disease-pressure conditions, and has minimal crop management requirements. These qualities make it an emergency crop in conflict zones (Gomes et al., 2004), and a potentially important component of agricultural diversification strategies for adaptation to climate change.

**Cereal cultivars resistant to insect pests have reduced yield losses.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | +1 to +4 | G | USA,CWANA |

Aphids, sun pest and Hessian fly are among the most serious pests of cereals worldwide (Miller et al., 1989; Ratcliffe and Hatchett, 1997; Mornhinweg et al., 2006). Hessian fly attacks result in yield losses of up to 30% in USA and Morocco, with estimated damage exceeding US $20 m per annum (Lafever et al., 1980; Lhaloui et al., 2005; Azzam et al., 1997). The most effective means of combating this pest has been found to be the development of cultivars with genes H1 to H31 for host plant resistance (antibiosis, antixenosis and tolerance) (Ratcliffe and Hatchett, 1997; Williams et al., 2003; Ohm et al., 2004). The development of wheat varieties resistant to the Hessian fly has been estimated to generate an internal rate of return of 39% (Azzam et al., 1997). A similar resistance approach has been taken with Russian wheat aphid, *Diuraphis noxia*) in wheat and barley in the US (Mornhinweg et al., 2006), and with soybean aphid (*Aphis glycines*). Storage pests, such as weevils, lower the quality of stored grain and seeds, and damage leads to secondary infection by pathogens, causing major economic losses. Host plant resistance has been identified against weevils, such as the maize weevil, *Sitophilus zeamais* and *Callosobruchus* spp., which also affect legumes e.g., cowpea (Dhliwayo et al., 2005).

**Ethnoveterinary medicine for livestock could be a key veterinary resource.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | +1 to +4 | G | USA, CWANA |

Ethnoveterinary medicine (EVM) differs from the paternal approach by considering traditional practices as legitimate and seeking to validate them (Köhler-Rollefson and Bräunig, 1998). Systematic studies on EVM can be justified for three main reasons (Tabuti et al., 2003), they can generate useful information needed to develop livestock healing practices and methods that are suited to the local environment, can potentially add useful new drugs to the pharmacopoeia, and can contribute to biodiversity conservation.

*3.2.1.2.3 Improving quality and post-harvest techniques*

Traditionally, breeding was concerned primarily with yield, adaptation and disease/pest resistance rather than quality and post-harvest processing traits. In recent years, more emphasis has been given to quality, especially user-defined quality (i.e. consumer acceptance), industrial processing and bioenhancement. In particular, more breeding programs are now focusing on fodder and forage quality, and not just grain quality.

**Breeding for improved and enhanced quality is increasingly important.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H | C | 0 to +1 | G | Maize, rice |

Bioenhancement or biofortification is not a new concept, e.g. CIMMYT has worked on quality protein maize (QPM) for more than two decades, but concerns over micronutrient deficiencies (Bouis et al., 2000; Graham et al., 1999; www.harvestplus.org) in modern diets are driving renewed interest. Vitamin A deficiency affects 25% of all children under 5 in developing countries (i.e., 125,000 children), while anemia (iron deficiency) affects 37% of the world's population (www.harvestplus.org). Using genetic manipulation, genes for higher vitamin A have been inserted into rice (Golden Rice) (Guerinot, 2000), and efforts are underway to produce micronutrient-dense iron and zinc varieties in rice.

**Breeding for fodder and forage quality and yield is becoming more important.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H | E | 0 to +2 | R | India |

The recognition that most small-scale farmers use crops for multiple-purposes and the rapid expansion in livestock production has resulted in breeding programs that target fodder and forage quality and yield. For example, Quantitative Trait Loci (QTLs) for stover quality traits that can be used in MAB have been identified in millet (Nepolean et al., 2006); ICRISAT now tests sorghum, millet and groundnut breeding lines for fodder quality and production.

**A large number of post-harvest technologies have been developed to improve the shelf life of agricultural produce**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H | A | +1to +3 | G | Developed countries |

Post-harvest technologies include canning, bottling, freezing, freeze drying, various forms of processing (FFTC, 2006), and other methods particularly appropriate for large commercial enterprises. Studies on the effects of storage atmosphere, gaseous composition during storage, post-harvest ethylene application and UV irradiation, and effect of plant stage on the availability of various micronutrients in different foods are being examined to provide increased understanding of the sensitivity of micronutrient availability to the ways in which foods are handled, stored and cooked (Welch and Graham, 2000; Brovelli, 2005).

3.2.1.3 Recent biotechnologies: MAS, MAB and Genetic Engineering

Nucleic acid technologies (Table 3.2) and their application in genomics is beginning to have an impact on plant (Baenziger et al., 2006; Swamininathan, 2006) and animal breeding, both through increased knowledge of model and crop species genomes, and through the use of Marker-Assisted Selection (MAS) or Backcrossing (MAB).

**[Insert Table 3.2]**

Plants

**The tools and techniques developed by applied modern biotechnology are beginning to have an impact on plant breeding and productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +3 | G | Many crops |

The use of genomic-based breeding approaches are already widespread (e.g. Generation Challenge Program: http://www.generationcp.org/index.php), particularly Marker Assisted Selection (MAS) or Backcrossing (MAB). CIMMYT, for example, routinely uses five markers and performs about 7000 marker assays per year (Reynolds and Borlaug, 2006). These markers include two for cereal cyst nematode, one for barley yellow dwarf, one to facilitate wide crossing and one for transferring disease resistance from different genomes. Likewise, ICRISAT routinely uses MAS to incorporate genes for downy mildew resistance in pearl millet (ICRISAT, 2006). MAS can shorten the breeding cycle substantially and hence, the economic benefits are substantial (Pandey and Rajatasereekul, 1999). Using MAS, it took just over three years to introduce downy mildew resistance compared to nearly nine years by conventional breeding (ICRISAT, 2006). QTLs identified for submergence tolerance in rice have also been fine-mapped and gene-specific markers identified (Xu et al., 2006), shortening the breeding cycle with MAB to 2 years. At present, as in the examples above, most MAS is with major genes or qualitative traits and MAS is likely to be most useful in the near future to transfer donor genes, pyramid resistance genes and finger print MVs (Koebner and Summers 2003; Baenziger et al., 2006). To date, MAS has been less successful with more complex, quantitative traits, particularly drought tolerance (Snape, 2004; Steele et al., 2006).

**Knowledge of gene pathways and regulatory networks in model species is starting to have impacts on plant breeding.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +2 | G | Widespread applicability |

The genome of the model plant species *Arabidopsis* and its function have been studied in great detail. One of the most important traits in crop plants is the timing of flowering and crop duration, which determines adaptation. Genes that control the circadian rhythm and the timing of flowering have been extensively studied in *Arabidopsis* (Hayama and Coupland, 2004; Corbesier and Coupland, 2005; Bernier and Perilleux, 2005) and modeled (Welch et al., 2003; Locke et al., 2005). Homologues of key flowering pathway genes have been identified in rice and many other crop plants, and flowering pathways and the control of flowering time better understood (Hayama and Coupland, 2004), thus providing an opportunity to manipulate this pathway. Drought resistance has also been studied in *Arabidopsis* and two genes, the DREB gene (Pellegrineschi et al., 2004) and the *erecta* gene (Masle et al., 2005); these confer some tolerance to water deficits or increase water-use efficiency. Promising constructs of the DREB gene have been produced in rice, wheat and chickpea (Bennett, 2006).

**Modern biotechnology, no matter how successful at increasing yield or increasing disease and pest resistance, will not replace the need for traditional crop breeding, release and dissemination processes.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | A | 0 to +2 | G | Widespread applicability |

The products of most current biotechnology research are available to farmers through the medium of seed, and will therefore still go through current national registration, testing and release procedures. The same constraints to adoption by farmers apply for GM and non-GM organisms. There are arguments for shortening testing and release procedures in the case of existing varieties that have their resistance ‘updated’ against new strains of disease. In India a new version of a widely grown pearl millet variety (HHB67)was approved for release that incorporates resistance to a new and emerging race of downy mildew (identified by DNA finger-printing and incorporated using MAS backcrossing) (ICRISAT, 2006). Only a few countries currently have biosafety legislation or research capacities that allow for testing GM crops and assessing and understanding the structure of wild genetic resources (see 3.2.2.2.3).

Livestock

**There have been rapid developments in the use of molecular genetics in livestock over the past few decades.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E, D | C | 0 to +3 | G | Widespread applicability |

Good progress has been made in developing complete genome maps for the major livestock species (initial versions already exist for cattle and poultry). DNA-based tests for genes or markers affecting traits that are difficult to measure currently, like meat quality and disease resistance, are being sought. However, genes of interest have differing effects in breeds/lines from different genetic backgrounds, and in different production environments. When these techniques are used, it is necessary to check that the expected benefits are achieved. Because of the cost-effectiveness of current performance recording and evaluation methods, new molecular techniques are used to augment, rather than replace, conventional selection methods with the aim of achieving, relevant, cost-effective, publicly acceptable breeding programs.

**Biotechnologies in the livestock sector are projected to have a future impact on poverty reduction.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, D | F | -2 to +4 | G | North v South |

At present, rapid advances in biotechnologies in both livestock production and health hold much promise for both poverty alleviation and environmental protection (Makkar and Viljoen, 2005). Areas of particular note include new generation vaccines and transgenic applications to enhance production (Cowan and Becker, 2006).Polymerase chain reaction (PCR) technology can be utilized to reduce the methane production of cattle (Cowan and Becker, 2006) and grain crops can now be genetically manipulated to lower nitrogen and phosphorous levels in animal waste. Such tools can also be utilized to characterize indigenous animal genetic resources to both understand key factors in disease resistance and adaptation and further protect local breeds. Nevertheless, the impact on poverty reduction and safety of many of these technologies is currently unknown (Nangju, 2001; Cowan and Becker, 2006).

3.2.1.4 Genetic engineering

Modern biotechnological discoveries include novel genetic engineering technologies such as the injection of nucleic acid into cells, nuclei or organelles; recombinant DNA techniques (cellular fusion beyond the taxonomic family and gene transfer between organisms) (CBD, 2000). The products of genetic engineering, which may consist of a number of DNA sequences assembled from a different organism, are often referred to as ‘transgenes’ or 'transgene constructs'. Public research organizations in both high- and low-income countries and the private sector are routinely using biotechnology to understand the fundamentals of genetic variation and for genetic improvement of crops and livestock. Currently, most of the commercial application of genetic engineering in agriculture comes through the use of genetically modified (GM) crops. The commercial use of other GM organisms, such as mammals, fish or trees is much more limited.

Plants

**Adoption of commercially available GM commodity crops has primarily occurred in chemical intensive agricultural systems in North and South America.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | Not yet known | R | Controlled by government regulation |

The two dominating traits in commercially available crop plants are resistance to herbicides and insects (Bt). Resistance is primarily to two broad spectrum herbicides: glyphosate and glufosinate. Resistance against insects is based on traits from *Bacillus thuringiensis* (Bt). The four primary GM crop plants in terms of global land area are soybean (57%), maize (25%), cotton (13%) and canola/oilseed rape (5%) (James, 2006) with the the US (53%), Argentina (18%), Brazil (11%) and Canada (6%) as major producers. In Asia, GM cotton production occurs in smaller scale systems in India (3.7%) and China (3.5%) (James, 2006). Sixteen other countries make up the remaining area (4.8%) of global GM crop production (James, 2006). GM crops are mostly used for extractive products (e.g. lecitines and oil from soy bean, starch from maize) or for processed products such as cornflakes, chips or tortillas. Whole grain GM maize is only consumed as 'food aid' sent to famine areas, while some parts of GM cotton plants are used as animal feed. A great diversity of novel traits and other crops plants (e.g. for pharmaceutical and industrial purposes) are under development and their impacts will need to be evaluated in the future. The main challenge here will be to keep GM pharma and industrial crops separate from crops for food (Ellstrand, 2003; Ledford, 2007).

**Environmental impacts of GM crops are inconclusive.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, D | C | Not yet known | G,R | Complex interacting factors being identified |

Both negative and benign impacts have been reported, depending on the studied system and the chosen comparator. Contradictory reports from laboratory and field studies with GM crops (Bt- and herbicide resistant) show a great diversity of impacts on non-target organisms, including arthropods and plants (Burke, 2003; O'Callaghan et al., 2005; Squire et al., 2005; Hilbeck and Schmidt, 2006; Sanvido et al., 2006; Torres and Ruberson, 2006). Some reports claim that GM crops do not adversely affect biodiversity of non-target organisms, or have only minor effects, while others report changes in the community composition of certain biocontrol taxa (Torres and Ruberson, 2006). Some reports find that the key experiments and fundamental issues related to environmental impacts are still missing (Wolfenbarger and Phifer, 2000; Snow et al., 2005). Another controversial topic surrounds claims that GM crops significantly reduce pesticide use and, thus, help to conserve biodiversity (Pray et al., 2002; Huang et al., 2002; Qaim and Zilberman, 2003; Bennett et al., 2004ab; Morse et al., 2004). Contradictory evidence has also been provided (e.g. Benbrook, 2003, 2004; Pemsl et al., 2004, 2005), which in part may be attributable to the dynamic condition of pest populations and their outbreaks over time. A further complication arises from the development of secondary pests which reduce the benefits of certain Bt crops (Qayum and Sakkhari, 2005; Wang et al., 2006). The effects of Bt crops on pesticide use and the conservation of biodiversity may depend on the degree of intensification already present in the agricultural system at the time of their introduction (Cattaneo et al., 2006; Marvier et al., 2007). A recent meta-analysis of 42 field studies (Marvier et al., 2007) in which scientists concluded that the benefits of Bt-crops are largely determined by the kind of farming system into which they are introduced, found that Bt-crops effectively target the main pest when introduced into chemical intensive industrial farming systems. This provides some support to the claim that Bt plants can reduce insecticide use. However, when Bt crops were introduced into less chemical intensive farming systems the benefits were lower. Furthermore when introduced into farming systems without the use of synthetic pesticides, (e.g. organic maize production systems), there were no benefits in terms of reduced insecticide use. In fact, in comparison with insecticide-free control fields, certain non-target taxa were significantly less abundant in Bt-crop fields. Most field studies were conducted in pesticide-intensive, large-scale monocultures like those in which 90% of all GM crops are currently grown (Cattaneo et al., 2006); consequently, these results have limited applicability to low-input, small-scale systems with high biodiversity and must be assessed separately. Introducing GM crops accompanied by an intensification strategy that would include access to external inputs could enhance benefits for small-scale systems (Hofs et al., 2006; Witt et al., 2006).

**Currently there is little, if any, information on ecosystem biochemical cycling and bioactivity of transgene products and their metabolites, in above and below ground ecosystems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | Not yet known | G | Widespread |

There are multiple potential routes for the entry of Bt-toxins into the ecosystem, but there is little information to confirm the expected spread of Bt-toxins through food chains in the field (Harwood et al., 2005; Zwahlen and Andow, 2005; Harwood and Obrycki, 2006; Obrist et al., 2006). One expected route would be embedded in living and decaying plant material, as toxins leach and exude from roots, pollen, feces from insects and other animals. There is confirmation of the presence of Bt toxin metabolites in feces of cows fed with Bt-maize feed (Lutz et al., 2005). Several experiments have studied the impacts of Bt-crop plant material on soil organisms with variable results ranging from some effects, only transient effects, to no effects (e.g. Zwahlen et al., 2003; Blackwood and Buyer, 2004). However, to date there has not been a study of the ecosystem cycling of Bt toxins and their metabolites, or their bioactivity.

**Evidence is emerging of herbicide and insecticide resistance in crop weeds and pests associated with GM crops.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | Not yet known | G | Widespread |

Since 1995 there have been reports of an increase from 0 to 12 weed species developing resistance to glyphosate, the main broad spectrum herbicide used in GM crops from countries where herbicide-resistant GM crops are grown (van Gessel, 2001; Owen and Zelaya, 2005; Heap, 2007). In addition, the use of glyphosate has greatly increased since the introduction of herbicide tolerant crops. With the exception of Australia (http://www.ogtr.gov.au/rtf/ir/dir059finalrarmp1.rtf: 2006, Australian Gene Technology Act 2000) no resistance management plans are required for the production of herbicide resistant crops; management strategies are required for insect-resistant Bt-crops, in most countries where they are grown. There has been only one report of an insect pest showing resistance to one of the commonly used Bt-toxins (Gunning et al., 2005). Strategies are needed for efficient resistance management and the monitoring of the spread and impacts of GM-resistance genes in weed and pest populations.

**There are reported incidents of unintentional spread (via pollen and seed flow) of GM traits and crops.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, N, L, E, D | C | Not yet known | G, R | Worldwide, controlled by government enforcement of regulations |

The consequences from unintentional spread of GM traits and GM crops could be serious. GM traits and crops with varying levels of approval are spreading fast throughout the world; intentional spread occurs mainly through human transport and trade. However, a number of unapproved varieties have also spread unintentionally, creating potential genetic contamination problems that countries must be increasingly prepared to tackle (www.gmcontaminationregister.org/ or link through CBD Cartagena Protocol Biosafety Clearinghouse). In 2006, unapproved GM traits which originated inrice field trials in the US and China were found in commercial rice sold in European supermarkets; consequently farmers suffered serious economic losses due to subsequent bans on imports. Later, there were additional costs in both countries for certification of freedom from unapproved GM traits. Similar controversy followed the discovery of transgenes in landraces of maize in Mexico (Quist and Chapela, 2001; Kaplinski, 2002; Kaplinski et al., 2002; Metz and Fütterer, 2002ab; Quist and Chapela, 2002; Suarez, 2002; Worthy et al., 2002). There is also evidence of increased invasiveness/weediness as a result of the gene flow of GM traits, such as herbicide and insect resistance, into cultivated or wild and weedy relatives (e.g. Snow et al., 2003; Squire et al. 2005), making them more difficult to control (Cerdeira and Duke, 2006; Thomas et al., 2007). In Canada, double and triple herbicide resistant oilseed rape volunteers occur in other crops, including other resistant soybeans and maize requiring the use of herbicides other than glyphosate or glufosinate (e.g. Hall et al., 2000; Beckie et al., 2004). The same is true for herbicide resistant -crop volunteers in the US (e.g. Thomas et al., 2007). In Canada, organic oilseed rape production in the prairies was largely abandoned because of widespread genetic contamination with transgenes or transgenic oilseed rape (Friesen et al., 2003; Wong, 2004; McLeod-Kilmurray, 2007).

**Current risk assessment concepts and testing programs for regulatory approval are incomplete and still under development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | Not yet known | G | Wide applicability |

Risk assessment concepts for genetically modified (GM) plants exist in regulations, guidelines and discussion documents in some countries, e.g., USA (Rose, 2007), Canada (Canadian Food Inspection Agency, 2004), the European Union (EC, 2002; EFSA, 2004, 2007) and internationally (OCED, 1986, 1993; Codex Alimentarius, 2003). Some groups have expressed the view that pre-market testing for environmental risks of GM crops to non-target organisms needs to follow protocols for chemicals, such as pesticides (Andow and Hilbeck, 2004), and have called for alternative approaches. A number of concepts are currently being developed and discussed (Hilbeck and Andow, 2004; Andow et al., 2006; Garcia-Alonso et al., 2006; Hilbeck et al., 2006; Romeis et al., 2006).

**The development of regulatory and scientific capacity for risk assessment as well as training for farmers on proper technology use is needed to enable developing countries to benefit from biotechnology.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, N, L, E, S, D | B | Not yet known | G,R | Mainly in developing countries |

Realization of the benefits of GM technology in the countries will be closely linked to the understanding of the technology and the involved biosafety issues at all levels (e.g. policy, regulation, science, legal, socioeconomic, farm) and with the countries capabilities to implement the Cartagena Protocol on Biosafety (www.cbd.int/biosafety/default.shtml). All signatory countries are currently working on the implementation of the Protocol within national contexts. However, developing countries lack national capacities on almost all involved fields, particularly+ biosafety. A number of capacity development projects for the implementation of the Cartagena Protocol on Biosafety are currently on-going (www.gmo-guidelines.info; www.biosafetrain.dk/, www.ribios.ch; www.unep.ch/biosafety/) but need to be complemented by efforts to develop academic educational programs for biosafety degrees ( www.cbd.int/doc/newsletters/bpn/bpn-issue02.pdf).

Livestock/fish

**Production of transgenic livestock for food production is technically feasible, but at an earlier stage of development than the equivalent technologies in plants.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E, D | C | Not yet known | G | Widespread applicability |

Progress has been made in developing transgenic technologies in animals, including fish. To date, at least 10 species of fish have been modified for enhanced growth, including common carp, crucian carp, channel catfish, loach, tilapia, pike, rainbow trout, Atlantic salmon, Chinook salmon, and sockeye salmon (Dey, 2000). These, however, have yet to be approved for commercialization (Aerni, 2001 as cited in Delgado et al., 2003). In animals there is also a focus on disease resistance through transferring genes from one breed or species to another. Coupled with new dissemination methods (e.g. cloning) these techniques are expected to dramatically change livestock production. However, there are many issues that need to be addressed regarding the lack of knowledge about candidate genes for transfer, as well as ethical and animal welfare concerns and a lack of consumer acceptance in some countries. Other constraints include the lack of an appropriate industry structure to capitalize on the technologies, and the high cost of the technologies.

3.2.1.5 Advances in soil and water management

Fertilizer and irrigation AKSTs have had a significant impact on agricultural production globally. The focus is currently on increasing the efficiency of resource use in order to reduce the negative environmental effects of over use and to reduce use of a diminishing resource.

Soil management

**The use of traditional natural fallows to sustainably increase the carrying capacity of the land is now uncommon.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | 0 to +4 | R | Mainly in the tropics |

Traditionally, degraded crop fields were restored by allowing native vegetation to regenerate as a natural fallow. Fallows restore biodiversity, improve soil permeability through root activity; return organic matter to the soil; protect against erosion by rain and wind, and provide protection from direct radiation and warming (Swift and Anderson, 1993; Swift et al., 1996). Natural fallows of this sort are no longer applicable in most places because population pressure is high; consequently shorter and more efficient fallows using leguminous shrubs and trees are being developed (Kwesiga et al., 1999). When soil fertility is severely depleted, some external mineral nutrients (phosphorus, calcium) or micronutrients may be needed to support plant growth and organic matter production.

**In many intensive production systems, the efficiency of fertilizer nitrogen use is low and there is significant scope for improvement with better management**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, L, E, D | E | -5 to -2 | G to L | Widespread |

The extent of soil degradation and loss of fertility is much greater in tropical than in temperate areas. Net nutrient balances (kg $ha^{-1}$ per 30 years) of NPK are respectively: -700, -100, -450 for Africa; and +2000, +700, +1000 for Europe and North America. Low fertilizer recovery efficiency can reduce crop yields and net profits, increase energy consumption and greenhouse gas emissions, and contribute to the degradation of ground and surface waters (Cassman et al., 2003). Among intensive rice systems of South and Southeast Asia, crop nitrogen recovery per unit applied N averages less than 0.3 kg $kg^{-1}$ with fewer than 20% of farmers achieving 0.5 kg $kg^{-1}$ (Dobermann and Cassman, 2002). At a global scale, cereal yields and fertilizer N consumption have increased in a near-linear fashion during the past 40 years and are highly correlated. However, large differences exist in historical trends of N fertilizer usage and nitrogen use efficiency (NUE) among regions, countries, and crops. Interventions to increase NUE and reduce N losses to the environment require a combination of improved technologies and carefully crafted local policies that contribute to the adoption of improved N management practices. Examples from several countries show that increases in NUE at rates of 1% yr-1 or more can be achieved if adequate investments are made in research and extension (Dobermann, 2006). Worldwide, NUE for cereal production is approximately 33% (Raun and Johnson, 1999). Many systems are grossly over-fertilized. Irrigated rice production in China consumes around 7% of the global supply of fertilizer nitrogen. Recent on-farm studies in these systems suggest that maximum rice yields are achieved at N fertility rates of 60-120 kg N $ha^{-1}$, whereas farmers are fertilizing at 180-240 kg N $ha^{-1}$ (Peng et al., 2006).

**Good soil management enhances soil productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | +1 to +3 | R | Especially important in the tropics |

In the tropics, the return of crop residues at a rate of 10-12 tonnes dry matter $ha^{-1}$ represents an input of 265 kg carbon $ha^{-1}$ in the upper 10 cm soil layer (Sá et al., 2001ab; Lal, 2004). Given an appropriate C:N ratio, this represents an increased water holding capacity of 65-90 mm, potentially a 5-12% increase in maize or soybean yield, and increased income of US $40-80 $ha^{-1}$ (Sisti et al., 2004; Diekow et al., 2005). Soil carbon and yields can be increased on degraded soils through conservation agriculture (e.g., no-till), agroforestry, fallows with N-fixing plants and cover crops, manure and sludge application and inoculation with specific mycorrhiza (Franco et al., 1992; Wilson et al., 1991. Organic matter can improve the fertility of soils by enhancing the cation exchange capacity and nutrient availability (Raij, 1981; Diekow et al., 2005).

**Poor nutrient recovery is typically caused by inadequate correspondence between periods of maximum crop demand and the supply of labile soil nutrients**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | B | +1 to +3 | L | Wide applicability |

The disparity between periods of maximum crop demand and the supply of labile soil nutrients (Cassman et al., 2003) can be exacerbated by over-fertilization (e.g. Peng et al., 2006; Russell et al., 2006). For elements like nitrogen which are subject to losses from multiple environmental pathways, 100% fertilizer recovery is not possible (Sheehy et al., 2005). Nevertheless, precision management tools like leaf chlorophyll measurements that enable real-time nitrogen management have been shown to reduce fertilizer N application by 20-30% while maintaining rice productivity (Peng et al., 1996; Balasubramanian et al., 1999; 2000; Hussain et al., 2000; Singh et al., 2002). From 1980 to 2000 in the US, maize grain produced per unit of applied N increased by more than 40%, with part of this increase attributed to practices such as split-fertilizer applications and pre-plant soil tests to establish site-specific fertilizer recommendations (Raun and Johnson, 1999; Dobermann and Cassman, 2002). Despite improved management practices, average N recovery in US maize remains below 0.4 kg N per kg fertilizer N (Cassman et al., 2002), indicating significant scope for continued improvement.

**Precision application of low rates of fertilizer can boost productivity among resource poor farmers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | 0 to +2 | N, R | Small-scale farms of the semi-arid tropics. |

Resource constraints prevent many small-scale farmers from applying fertilizer at rates that maximize economic returns. ICRISAT has been working in SSA to encourage small-scale farmers to increase inorganic fertilizer use and to progressively increase their investments in agricultural production. This effort introduces farmers to fertilizer use thorough micro-dosing, a concept based on the insight that farmers are risk averse, but will gradually take larger risks as they learn and benefit from new technologies (Dimes et al., 2005; Rusike et al., 2006; Ncube et al., 2007). Micro-dosing involves the precision application of small quantities of fertilizer, typically phosphorus and nitrogen, close to the crop plant, enhancing fertilizer use efficiency and improve productivity (e.g., 30% increase in maize yield in Zimbabwe). Yield gains are larger when fertilizer is combined with the application of animal manures, better weed control, and improved water management. Recent innovations have focused on formulating the single-dose fertilizer capsules.

**Grain legumes can provide a significant source of nitrogen fertility to subsequent non-leguminous crops.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, D | A, B | +1 to +5 | G | Widespread |

Nitrogen fertility is the most common constraint to crop productivity in many developing countries (Cassman et al., 2003). In industrialized countries, synthetic N fertilizer accounts for around 30-50% of the fossil fuel energy consumption in intensively cropped systems (Liska et al., 2007). Biological nitrogen fixation (BNF) from leguminous crops offers benefits in both intensive and non-intensive agricultural systems. Grain legumes are particularly attractive because they can provide an independent economic return, in addition to residual soil fertility benefits for subsequent crops. These residual benefits, however, are contingent on the amount of N that remains in the field after harvest. In Zimbabwe, sorghum grain yield following legumes increased by more than 1 tonnes $ha^{-1}$ compared to yield achieved with continuous sorghum production (e.g. 1.62 to 0.42 tonnes $ha^{-1}$). Other studies in Africa have also demonstrated the value of using grain legumes such as groundnuts to improve nitrogen fertility (Waddington and Karigwindi, 2001). However, degraded soils low in soil phosphorous may limit the effectiveness of BNF (Vitousek et al., 2002). In the United States, soybean provides between 65-80 kg N $ha^{-1}$ to subsequent grain crops and hence fertilizer applications can be reduced accordingly (Varvel and Wilhelm, 2003) (See 3.2.2.1.7).

Water management

**Potential per capita water availability has decreased by 45% since 1970.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -5 to -1 | G | Poor people in dry areas are most affected |

Due to population growth, the potential water availability decreased from 12900 $m^3$ per capita per year in 1970 to less than 7,800 $m^3$ in 2000 (CA, 2007). Freshwater available for ecosystems and humans globally is estimated at ~200 000 $km^3$ (Gleick, 1993; Shiklomanov, 1999), with the freshwater available for human consumption between 12500 and 14000 $km^3$ each year (Hinrichsen et al., 1998; Jackson et al., 2001). Groundwater represents over 90% of the world's readily available freshwater resource (Boswinkel, 2000). About 1.5 billion people depend upon groundwater for their drinking water supply (WRI, UNEP, UNDP, World Bank, 1998). The amount of groundwater withdrawn annually is roughly estimated at ~600-700 $km^3$, representing about 20% of global water withdrawals. The volume of water stored in reservoirs worldwide is estimated at 4286 $km^3$ (Groombridge and Jenkins, 1998). A large number of the world's population is currently experiencing water stress and rising water demands greatly outweigh greenhouse warming in defining the state of global water systems to 2025 (Vörösmarty et al., 2000).

**Water management schemes are resulting in increased efficiency of water use.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N,L,E,S | B | 0 to +4 | G | Wide applicability |

To enhance the efficiency of water management, different forms of water resources have been identified, partitioned and quantified by land use system (Falkenmark and Rockström, 2005): basin water is 'blue' water and contributes to river runoff, and green water, which passes through plants (Falkenmark, 2000). Land use changes can reallocate green water and alter the blue–green balance. There are a number of different strategies to improve water productivity values (production per unit of evapotranspiration) for both blue and green water: a) improve timing and increase the reliability of water supplies; b) improve land preparation and fertilizer use to increase the return per unit of water; c) reduce evaporative losses from fallow land, lakes, rivers and irrigation canals; (d) reduce transpiration losses from non-productive vegetation; e) reduce deep percolation and surface runoff; f) minimize losses from salinization and pollution; g) reallocate limited resources to higher-value users; and h) develop storage facilities (Molden et al., 2003; 2007b). The reallocation of water can have serious legal, equity and other social considerations. A number of policy, design, management and institutional interventions may allow for an expansion of irrigated area, increased cropping intensity or increased yields within the service areas. Possible interventions are reducing delivery requirements by improved application efficiency, water pricing and improved allocation and distribution practices (Molden et al., 2003).

**Small-scale, informal types of irrigation such as water harvesting and groundwater pumps can reduce risk of crop failure and increase yield.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L | B | +1 to +3 | R | Applicable in dry areas |

Water harvesting is a traditional water management technology with increasing importance and potential to ease water scarcity in many arid and semi-arid regions of world. The water harvesting methods applied depend on local conditions and include such widely differing practices as bunding, pitting, microcatchments, and flood and ground water harvesting (Prinz, 1996; Critchley and Siegert, 1991). On-farm water-productive techniques coupled with improved management options, better crop selection, appropriate cultural practices, improved genetic make-up, and socioeconomic interventions such as stakeholder and beneficiary involvement can help achieve increased crop yields (Oweis and Hachum, 2004), and reduce the risk of crop failure. Most of the techniques are relatively cheap and are viable options when irrigation water from other sources is not readily available or too costly and using harvested rainwater helps in decreasing the use of groundwater.

**Soil and moisture conservation, and micro-irrigation techniques have been developed to increase crop yields by small farmers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | B | +2 to +4 | N, R | Small-scale farms of the semi-arid tropics. |

Many soil and moisture conservation and micro-irrigation techniques have been developed to increase crop yields by small farmers. Soil and moisture conservation techniques include tillage practices, planting grasses, such as vetiver, and other living barriers, terracing, bunding and contour planting (Tripp, 2006). Micro-irrigation techniques include drip irrigation, basin planting or 'zai' pits, and the introduction of treadle pumps and water harvesting (Mupangwa et al., 2006). To reduce the quantities of water and nutrients used during crop establishment, ICRISAT and several NGO partners have promoted a 'conservation agriculture' package based on basin planting; small basins (approx. 3375 $cm^3$) are prepared during the dry season when labor demands are relatively low. Basin planting utilizes limited resources more efficiently by concentrating nutrients and water applications. For small-scale systems in dry areas of southern and western Zimbabwe, maize yields were 15-72% (mean = 36%) greater from basin planting than from conventional plowing and whole-field cultivation.

**In many urban areas across the world, sewerage is used as source of water and nutrients in urban and peri-urban agriculture.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H | B | -3 to -1 | L | Especially around large cities in developing countries |

Global assessments show that in developing countries only a minor part of the generated wastewater is treated while the large majority enters natural water bodies used for various purposes including irrigation. Recent studies suggest that at least 2-4 million ha of land are globally irrigated with untreated, treated, diluted or partially treated wastewater (Furedy, 1990; Drechsel et al., 2006). Generally, it is estimated that about 25-100% of food demand in an urban environment is met through production of food in the same setting (Birley and Lock, 1999), while about 10% of wastewater generated in towns has further use in urban agriculture. These estimates take account urban horticulture, aquaculture and livestock; 25-80% of urban households engage in some form of agriculture. In many developing countries in Asia, Africa and Latin America, sewage sludge has been used for some time (Furedy, 1990; Strauss, 2000). The risks associated with downstream recycling wastewaters are especially great in countries within arid and seasonally arid zones (Strauss, 2000). New WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (WHO, 2006) recognize the health issues concerning wastewater use in agriculture, but water pollution and its management will be an issue of concern for populations around the world for some time (Furedy, 1990; Dey et al., 2004).

**Many river basins can no longer sustainably supply water for agriculture and cities.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | -1 to -3 | R | Especially in the dry tropics |

Unsustainable use of water resources for irrigation means that extraction exceeds recharge. For example, large-scale irrigation since the 1960s has had devastating impacts on water resources and soil productivity in Central Asia. The water level of the Aral Sea has dropped by 17 m, resulting in a 50% reduction in its surface area and a 75% reduction in its volume. The resulting economic and health impacts to the Aral Sea coastal communities have also been serious (http://www.fao.org/ag/agl /aglw/aquastat/regions/fussr/index8.stm).

3.2.1.6 Advances in ICT

**Innovations in information technology have been essential for progress in biotechnology.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H | A | 0 to +4 | R | Mainly in developed countries |

Genomics, proteomics and metabolomics generate large quantities of data that require powerful computers and large database storage capacities for effective use; advances in ICT have been fundamental to their success. The growth of the worldwide web has allowed data to be widely accessed and shared, increasing impact. The complexity and size of tasks such as describing the genome of model plants has led to global collaboration and data-sharing.

**Climate and crop modeling is positively affecting crop production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N,H | B | 0 to +2 | G | Widespread |

The increasing availability of climate data and the use of simulation models, globally, regionally and locally, are having a positive impact on agricultural production. Field-scale crop growth and yield simulation models can help define breeding traits and growing environments, and analyze G x E interactions (Muchow et al., 1994; van Oosterom et al., 1996; Sinclair et al., 2005). At a larger scale, global and regional climate models (GCMs and RCMs) are producing more accurate forecasts and there is collaboration between meteorologists and crop scientists on seasonal weather forecasts (Slingo et al., 2005; Sivakumar, 2006) ranging from months to weeks; these forecasts have proved of practical and financial benefit in countries such as Australia (Stone and Meinke, 2005). More attention needs to be given to providing forecasts to farmers as climate change increases in importance.

**Remote sensing and site-specific management benefit from ICT.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +2 | G | Widespread |

Site-specific management and precision agriculture benefits from ICT (Dobermann and Cassman, 2002; Dobermann et al., 2002), such as global positioning systems. Remote sensing and Geographic Information Systems enable detailed monitoring, evaluation, and prediction of land use changes (see 3.2.2.1.1).

### *3.2.2 Impacts of AKST on sustainability, through integrated technologies and the delivery of ecosystem services and public goods*

The second pathway to agricultural development has come from the grassroots of civil society and involved locally-based innovations that meet the needs of local people and communities. This pathway has its foundations in traditional farming systems and addresses the integration of social and environmental issues with agricultural production. With the realization that the globalized pathway was not leading to sustainable land use systems, numerous different types of organizations initiated efforts to bring about a change, however, the agriculture 'Establishment' has in general marginalized these efforts, and they have not been mainstreamed in policy, or in agribusiness. Nevertheless, public-funded research has increasingly become involved, as illustrated by the creation of NRM programs in CGIAR Centers and and other research centers with natural resource management mandates. These and other initiatives have now given credibility to Integrated Natural Resources Management (INRM), in various forms (e.g., agroforestry and ecoagriculture) and recognized the importance of, and need for, new scientific research agendas (INRM Committee of CGIAR).

3.2.2.1 Integrated natural resource management systems

Sustainable rural development research has taken different approaches to the integration of management technologies in the search for a more holistic agricultural system (e.g. Integrated Pest Management, Integrated Water Resources Management, Integrated Soil and Nutrient Management and Integrated Crop and Livestock Management). These concepts are not foreign to developing country farmers, who traditionally have implemented various mixed farming systems appropriate to the local ecology. Research has also examined many of the ways that farmers approached integrated farm management, through various forms of mixed cropping. Over the last 25 years, agroforestry research has recognized that for millennia trees have played a role in food production both as tree crops and as providers of ecological services. Organic farming has especially focused on organic approaches to pest control, soil health and fertility rather than the use of inorganic inputs. There is a growing recognition of the importance of maintaining a functional agroecosystem capable of providing ecological services, biodiversity conservation (MA, 2005c; Cassman et al., 2005), and public goods such as water resources, watershed management, carbon sequestration and the mitigation of climate change.

**Integrated Natural Resources Management (INRM) has provided opportunities for sustainable development and the achievement of development and sustainability goals.**

| GOALS<br>N, H, L, E, S | CERTAINTY<br>B | RANGE OF IMPACTS<br>+1 to +5 | SCALE<br>L, R | SPECIFICITY<br>Wide applicability |
|---|---|---|---|---|

There are good localized examples of INRM enhancing agricultural sustainability (e.g., Palm et al., 2005b). INRM, like Farming Systems Research (www.fao.org/farming systems/ifsa_mandate), aims at simultaneously improving livelihoods, agroecosystem resilience, agricultural productivity and the provision of environmental services by augmenting social, physical, human, natural and financial capital (Thomas, 2003). It focuses on resolving complex problems affecting natural resources management in agroecosystems by improving the capacity of agroecological systems to continuously supply a flow of products and services on which poor people depend. It does this by improving the adaptive capacity of systems (Douthwaite et al., 2004). INRM innovations help to restore biological processes in farming systems, greatly enhancing soil fertility, water holding capacity, improving water quality and management, and increasing micronutrient availability to farming communities (Sayer and Campbell, 2004), through such processes as the diversification of farming systems and local economies; the inclusion of local culture, traditional knowledge and the use of local species; use of participatory approaches with poor farmers to simultaneously address the issues of poverty, hunger, health/malnutrition, inequity and the degradation of both the environment and natural resources (Campbell and Sayer, 2003). INRM reduces vulnerability to risk and shocks (Izac and Sanchez, 2001) by combining concepts of natural capital and ecosystem hierarchy.

**Resource-conserving technologies have been demonstrated to benefit poor farmers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B, E | +1 to +3 | M-L | Wide applicability |

A study of projects involving IPM, INM, conservation tillage, agroforestry with multifunctional trees in farming systems, aquaculture within farming systems, water harvesting and integrated livestock systems (Pretty *et al*., 2006) has examined to what extent farmers can increase food production using low-cost and available technologies and inputs, and their impacts on environmental goods and services. The multilocational study, covering 3% of cultivated land in 57 developing countries, identified very considerable benefits in productivity, which were often associated with reduced pesticide use, enhanced carbon sequestration, increased water use efficiency in rainfed agriculture (Pretty et al., 2006). The study concluded that the critical challenge is to find policy and institutional reforms in support of environmental goods and services from resource conserving technologies that also benefit food security and income growth at national and household levels.

*3.2.2.1.1 Techniques and concepts*

A number of new research and monitoring techniques and tools have been developed for this relatively new area of INRM research and land management (see also 3.2.3.3).

**Remote sensing and geographical information systems have provided tools for the monitoring, evaluation and better management of land use systems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | A | 0 to +4 | L, R | Tools with wide applicability |

Monitoring land use and land use change is an integral component of sustainable development projects (Janhari, 2003; Panigrahy, 2003; Verma, 2003). Remote sensing and GIS can cost-effectively assess short- and long-term impacts of natural resource conservation and development programs (Goel, 2003). They also have useful applications in studies of (Millington et al, 2001) urbanization, deforestation, desertification, and the opening of new agricultural frontiers. For example, these technologies have been used to study the spread of deforestation, the consequences of agricultural development in biological corridors, the impact of refugee populations on the environment and the NRM impacts of public agricultural policies (Imbernon et al., 2005). Modeling can extrapolate research findings and develop simulations using data obtained through remote sensing and GIS (Chapter 4).

*3.2.2.1.2 Integrated Pest Management (IPM)*

IPM is an approach to managing pests and disease that simultaneously integrates a number of different approaches to pest management and can result in a healthy crop and the maintainence of ecosystem balance (Abate et al., 2000). IPM approaches may include genetic resistance, biological control and cultivation measures for the promotion of natural enemies, and the judicious use of pesticides (e.g. Lewis et al., 1997).

**The success of IPM is based on effective management, rather than complete elimination, of pests**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | B | +1 to +4 | N, L | Wide applicability |

Success is evaluated on the combination of pest population levels and the probability of plant injury. For example, when climatic conditions are conducive for disease, fungicide has been found to be ineffective in controlling *Ascochyta* blight of chickpeas (ICARDA, 1986), but when combined with host resistance, crop rotation and modified cultural practices, fewer fungicide treatments can be both more effective and more economical. As an alternative to pesticides, IPM is most beneficial in high-value crops because of additional labor costs, but when the labor costs are low or IPM is part of a wider strategy to improve yields, IPM can also be of value economically (Orr, 2003). IPM can result in reductions of pesticide use up to 99% (e.g. van Lenteren, 2000). When compared to unilateral use of pesticides, IPM provides a strategy for enhanced sustainability and improved environmental quality. This approach typically enhances the diversity and abundance of naturally-occurring pest enemies and also reduces the risk of pest or disease organisms developing pesticide resistance by lowering the single-dimension selection pressure associated with intensive pesticide use.

**IPM produces positive economic, social and environmental effects.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | B | +1 to +4 | M-L | Wide applicability |

The past 20 years have witnessed IPM programs in many developing countries, some of which have been highly successful (e.g. mealy bug in cassava, Waibel and Pemsi, 1999). Positive economic, social and environmental impacts of IPM are a result of lower pest control costs, reduced environmental pollution; higher levels of production and income and fewer health problems among pesticide applicators (Figure 3.6). IPM programs can positively affect food safety, water quality and the long-term sustainability of agricultural system (Norton et al., 2005). Agroforestry contributes to IPM through farm diversification and enhanced agroecological function (Altieri and Nicholls, 1999; Krauss, 2004). However, the adoption of IPM is constrained by technical, institutional, socioeconomic, and policy issues (Norton et al., 2005).

**[Insert Figure 3.6]**

**Within IPM, integrated weed management reduces herbicide dependence by applying multiple control methods to reduce weed populations and decrease damage caused by noxious weeds.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | B | 0 to +3 | L | Wide applicability |

In contrast to conventional approaches to weed management that are typically prophylactic and uni-modal (e.g. herbicide or tillage only), Integrated Weed Management (IWM) integrates multiple control methods to adaptively manage the population levels and crop damage caused by noxious weeds, thereby increasing the efficacy, efficiency, and sustainability of weed management (Swanton and Weise, 1991). IWM systems are typically knowledge intensive and make use of ecological principals. Examples of IWM elements include cultivars that are bred for competitive ability (Gibson et al., 2003), diverse crop rotations that provide a variety of selection and mortality factors (Westerman et al., 2005), and simple management changes like higher seeding rates, spatially-uniform crop establishment (Olsen et al., 2005), banded fertilizer placement (Blackshaw et al., 2004), and biological control, particularly when the weed is an exotic invader (Zimmermann and Olckers, 2003). The serious parasitic weed of cereal crops (*Striga* spp.) in Africa can be regulated in sorghum by varietal resistance (Tesso et al, 2006), and by bait crops, like *Sesbania sesban*, *Desmodium* spp*.* that trigger suicidal germination of *Striga* seed (Khan et al., 2007; Gatsby Charitable Foundation, 2005). Herbicide use in agriculture has not been markedly reduced by integrated weed management, as weed science has lagged behind pest and disease management initiatives in terms of developing the basic biological and ecological insights typically required for integrated management (Mortensen et al., 2000; Nazarko et al., 2005).

*3.2.2.1.3 Integrated water resources management (IWRM)*

IWRM acknowledges water resource management conflicts by using participatory approaches to water use and management; resource development and environmental protection (van Hofwegen and Jaspers , 1999). It recognizes that water use in agriculture, especially irrigation water, meets the needs of fisheries, livestock, small-scale industry and the domestic needs of people, while supporting ecosystem services (Bakker et al., 1999; CA, 2007).

**IWRM helps to resolve the numerous conflicts associated with water use and management; resource development and environmental protection**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | B | 0 to +3 | R | Wide applicability |

Examples of IWRM at the field scale include alternate tillage practices to conserve water and low-cost technologies such as treadle pumps (Shah et al., 2000), and water-harvesting structures. IWRM recognizes the need to integrate water management at the basin level and to promote the linkages between different water uses at this level. It supports river basin management to ensure optimal (and efficient) allocation of water between different sectors and users. Through these approaches, IWRM has achieved a better balance between protecting the water resources, meeting the social needs of users and promoting economic development (Visscher et al., 1999).

**Natural Sequence Farming is restoring the hydrological balance of dryland farms in Australia.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | D | 0 to +3 | L | Wide applicability in dry areas |

Many agricultural landscapes in Australia are facing a land degradation crisis as a result of increasing salinity, soil acidification and erosion, coupled with severe drought, costing the economy 2.4 billion year$^{-1}$ (CRC Soil and Land Management 1999; Boulton, 1999, 2003). Much of this degradation has been caused by land clearance, clearance of waterways, and inappropriate European farming methods (Erskine, 1999; Erskine and Webb, 2003). Natural Sequence Farming is based on an understanding of how water functions in and hydrates the floodplain and involves techniques to slow down the drainage of water from the landscape and reinstate more natural hydrological processes (Andrews, 2005). The reported impacts (www.naturalsequence farming.com) of this have included increased surface and subsurface water storage, reduced dependence on borehole water from aquifers, significantly reduced salinity, improved productive land capacity, recharged aquifers, increased water use efficiency, increased farm productivity with lower water inputs, reduced runoff during peak inflows, and reduced use of pesticides (85%), fertilizers (20%) and herbicides (30%).

**Forestry has a role in regulating water supplies for agriculture and urban areas.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | B | 0 to +2 | R | Wide applicability |

The deforestation of watersheds has led to flooding; landslides; downstream siltation of waterways, wetlands and reefs and water shortages. However, the role of forests in regulating the availability of water resources involves a complex set of relationships involving site-specific functions of slope, soil type and surface cover, associated infrastructure and drainage, groundwater regimes, and rainfall frequency and intensity (Calder, 2005). Water quality from forest catchments is well recognized as better than that from most alternative land uses (Hamilton and King, 1983; Calder, 2005). In spite of the lack of clarity of land use-hydrological relations, payment systems or markets for watershed services are becoming popular in urban areas. For example, New York City has been assisting farmers to change land use, and in doing so has avoided the cost of constructing a large water purification plant.

*3.2.2.1.4 Integrated soil and nutrient management (ISNM)*

There are multiple pathways for loss of soil nutrients from agroecosystems, including crop harvest, erosion, and leaching. Soil nutrient depletion is one of the greatest challenges affecting the sustainability and productivity of small-scale farms, especially in sub-Saharan Africa. Globally, N, P and K deficits per hectare per year have been estimated at an average rate of 18.7, 5.1, and 38.8 kg, respectively (Lal et al., 2005). In 2000, NPK deficits occurred respectively on 59%, 85%, and 90% of harvested area. Total annual nutrient deficit (in millions of tonnes) was 5.5 N, 2.3 P, and 12.2 K; this was associated with a total potential global production loss of 1,136 million tonnes $yr^{-1}$ (Lal et al., 2005). Methods for restoring soil fertility range from increased fertilizer use to application of organic amendments like compost or manure. Applied in sufficient and balanced quantities, soil amendments may also directly and indirectly increase soil organic matter (see also 3.2.1.5). In addition to providing a source of plant nutrition, soil organic matter can improve the environment for plant growth by improving soil structure. A well-structured soil typically improves gas exchange, water-holding capacity, and the physical environment for root development.

**Agriculture has accelerated and modified the spatial patterns of nutrient use and cycling, especially the nitrogen cycle**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | -3 to +3 | G | Wide applicability |

Nitrogen fertilizer has been a major contributor to improvements in crop production. In 2000, 85 million tonnes of N were used to enhance soil fertility (Figure 3.1b). The use of N fertilizers affects the natural N cycle in the following ways:

1) increases the rate of N input into the terrestrial nitrogen cycle;

2) increases concentrations of the potent greenhouse gas $N_2O$ globally, and increases concentrations of other N oxides that drive the formation of photochemical smog over large regions of Earth;

3) causes losses of soil nutrients, such as calcium and potassium, that are essential for the long-term maintenance of soil fertility;

4) contributes substantially to the acidification of soils, streams, and lakes; and

5) greatly increases the transfer of N through rivers to estuaries and coastal oceans.

In addition, human alterations of the N cycle have increased the quantity of organic carbon stored within terrestrial ecosystems; accelerated losses of biological diversity, especially the loss of plants adapted to efficient N use, and the loss of the animals and microorganisms that depend on these plants; and caused changes in the composition and functioning of estuarine and near-shore ecosystems, contributing to long-term declines in coastal marine fisheries (Vitousek et al., 1997).

**Innovative soil and crop management strategies can increase soil organic matter content, hence maintaining or enhancing crop performance.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | +1 to +5 | G | Especially important in the tropics |

The organic matter content of the world's agricultural soils is typically 50-65% of pre-cultivation levels (Lal, 2004). Strategies to increase soil organic matter (carbon) include the integration of crop and livestock production in small-scale mixed systems (Tarawali et al., 2001; 2004); no-till farming; cover crops, manuring and sludge application; improved grazing; water conservation and harvesting; efficient irrigation; and agroforestry. An increase of 1 tonnes in soil carbon on degraded cropland soils may increase crop yield by 20 to 40 kg $ha^{-1}$ for wheat, 10 to 20 kg $ha^{-1}$ for maize, and 0.5 to 1 kg $ha^{-1}$ for cowpeas. The benefits of fertilizers for building soil organic matter through enhanced vegetation growth only accrue when deficiencies of other soil nutrients are not a constraint.

**No-tillage and other types of resource-conserving crop production practices can reduce production costs and improve soil quality while enhancing ecosystem services by diminishing soil erosion, increasing soil carbon storage, and facilitating groundwater recharge.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | B | 0 to +3 | R | Mostly applied in dry areas temperate/sub-trop zone |

Low-External Input Sustainable Agriculture (LEISA) is a global initiative aimed at the promotion of more sustainable farming systems (www.leisa.info). In the US, more than 40% of the cultivated cropland uses reduced or minimum tillage. At the global scale, no-till is employed on 5% of all cultivated land (Lal, 2004), reportedly covering between 60 million ha (Harington and Erenstein, 2005; Dumanski et al., 2006; Hobbs, 2006) and 95 million ha (Derpsch, 2005). Minimum tillage is a low-cost system and this drives adoption in many regions. No-till can reduce production costs by 15-20% by eliminating 4-8 tillage operations, with fuel reductions of up to 75% (Landers et al., 2001; McGarry, 2005). Conservation agriculture, which combines no-till with residue retention and crop rotation, has been shown to increase maize and wheat yields in Mexico by 25–30% (Govaerts et al., 2005). In the USA, the adoption of no-till increases soil organic carbon by about 450 kg C $ha^{-1}$ $yr^{-1}$, but the maximum rates of sequestration peak 5-10 yrs after adoption and slow markedly within two decades (West and Post, 2002). In the tropics soil carbon can increase at even greater rates (Lovato et al., 2004; Landers et al., 2005) and in the Brazilian Amazon integrated zero-till / crop-livestock-forest management are being developed for grain, meat, milk and fiber production (EMBRAPA, 2006). On the down-side, no-till systems often have a requirement for increased applications of herbicide and can be vulnerable to pest and disease build-up (e.g. wheat in America in late 1990s).

**Short-term improved fallows with nitrogen-fixing trees allow small-scale farmers to restore depleted soil fertility and improve crop yields without buying fertilizers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | +2 to +4 | R | Especially important in Africa |

Especially in Africa, short-rotation (2-3 years), improved agroforestry fallows with nitrogen-fixing trees/shrubs (e.g. *Sesbania sesban* and *Tephrosia vogelii*) can increase maize yield 3-4 fold on severely degraded soils (Kwesiga et al., 1999; Cooper et al., 1996). Unlike hedgerow inter-cropping, which as a high labor demand, these fallows are well adopted (Jama *et al*., 2006). Similar results can be achieved with legume trees and rice production in marginal, non-irrigated, low yield, conditions. The use of these improved fallows to free small-scale maize farmers from the need to purchase N fertilizers is perhaps one of the greatest benefits derived from agroforestry (Buresh and Cooper, 1999; Sanchez, 2002) and is a component of the Hunger Task Force (Sanchez et al., 2005) and the Millennium Development Project (Sachs, 2005). By substantially increasing maize yields in Africa, these easily-adopted fallows can reduce the gap between potential and achieved yields in maize.

**Deeply-rooted, perennial woody plants have greater and very different positive impacts on soil properties, compared with shallow-rooted annual crops**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | +2 to +4 | G | Wide applicability: important in the tropics |

The perennial habit of trees, shrubs and vines reduces soil erosion by providing cover from heavy rain and reducing wind speed. Their integration into farming systems also creates a cool, shady microclimate, with increased humidity and lower soil temperatures (Ong and Huxley, 1996; Ong et al., 1996; van Noordwijk et al., 2004). The deep and widespread roots both provide permanent physical support to the soil, and aid in deep nutrient pumping, decreasing nutrient losses from leaching and erosion (Young, 1997; Huxley, 1999). Trees also improve soils by nutrient recycling, increasing organic matter inputs from leaf litter and the rapid turnover of fine roots. This improves soil structure and creates ecological niches in the soil for beneficial soil microflora and symbionts (Lapeyrie and Högberg, 1994; Mason and Wilson, 1994; Sprent, 1994). Additionally, leguminous trees improve nutrient inputs through symbiotic nitrogen fixation. These tree attributes have been a dominant focus of agroforestry systems (Young, 1997). Most of the benefits from trees come at the expense of competition for light, water and nutrients (Ong et al., 1996). Consequently a net benefit only occurs when the tradeoffs (ecological, social and economic) are positive.

**Harnessing the symbiotic associations between almost all plants and the soil fungi (mycorrhizas) on their roots is beneficial to crop growth and soil nutrient management.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | +2 to +4 | G | Wide applicability: important in the tropics |

Many agricultural practices (land clearance, cultivation, fertilizer and fungicide application) have negative impacts on mycorrhizal populations, affecting the species diversity, inoculum potential, and the fungal succession. Techniques to harness the appropriate fungi, ectomycorrhizas on gymnosperms and some legumes (Mason and Wilson, 1994), and endomycorrhizas on most other plants (Lapeyrie and Högberg, 1994), include the conservation of natural soil inoculum and the inoculation of nursery stock prior to planting (Mason and Wilson, 1994). These techniques are critical for sustainable production as mycorrhizal associations are essential to plant establishment and survival, especially in degraded environments. It is now recognized that the soil inoculum of these fungal species is an important component of the soil biodiversity that enhances the sustainable function of natural ecosystems and agroecosystems (Waliyar et al., 2003).

**Extensive herding, the most widespread land use on earth, is more sustainable than commonly portrayed.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | +1 to +3 | L | Especially important in dry Africa |

Pastoralism is a widespread, ancient and sustainable form of land use. Mobile and extensive herding is highly compatible with plant and animal diversity (Maestas et al., 2003). When returns to livestock are sufficient, herding can compete well economically with other forms of farming, allowing land to remain open and lightly used (Norton-Griffiths et al., 2007). Land degradation by overgrazing has been overstated with livestock playing a much smaller negative role than climate in constraining productivity in drier rangelands (Ellis and Swift, 1988; Oba et al., 2000), particularly in Africa. However, in wetter rangelands, feedbacks between livestock and vegetation can be strong and sometimes negative (Vetter, 2005). Degradation most commonly occurs when crop farming extends into marginal lands, displacing herders (Geist and Lambin, 2004) (See 3.2.2.1.9).

*3.2.2.1.5 Integrated crop and livestock systems*

Worldwide, livestock have traditionally been part of farming systems for millennia. Integrated systems provide synergy between crops and livestock, with animals producing manure for use as fertilizer and improvement of soil structure (as well as a source of fuel), while crop by-products are a useful source of animal and fish food. In addition, fodder strips of grasses or fodder shrubs/trees grown on contours protect soil from erosion. The production of meat, milk, eggs and fish within small-scale farms generates income and enriches the diet with consequent benefits for health. On small farms, a few livestock can be stall-fed, hence reducing the negative impacts of grazing and soil compaction.

**Integrated crop and livestock production is an ancient and common production system.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | +1 to +3 | G | Worldwide applicability |

Close linking of crops and livestock in integrated systems can create an win-win with greater productivity and increased soil fertility (McIntire et al., 1992, Tarawali et al., 2001). Without this linkage, soil fertility can fall in cereal-based systems and surplus livestock manure is wasted (Liang et al., 2005). Linking crops and livestock forms a ‘closed’ nutrient system that is highly efficient. Crop-livestock systems are usually horizontally and vertically diverse, providing small habitat patches for wild plants and animals (Altieri, 1999) and greater environmental sustainability than crop monocultures (Russelle et al., 2007).

**In small-scale crop – livestock systems, fodder is often a limiting resource, which can be supplemented by tree/shrub fodder banks.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | +1 to +3 | R | Worldwide applicability |

In Kenya, tree-fodder from *Calliandra calothyrsus* grown in hedgerows and neglected niches has overcome the constraint of inadequate and low-quality feed resources and improved milk production and increasing income of around 1000 farmers by US $98-124 per year (Franzel et al., 2003). Three kg of *C. calothyrsus* fodder equals 1 kg of concentrate giving a yield of >10kg milk $d^{-1}$ with a buttermilk content of 4.5%. Likewise, in the Sahel *Pterocarpus erinaceus* and *Gliricidia sepium* are grown in fodder banks as a dry season resource for cattle and goats and this fodder is also traded in local markets (ICRAF, 1996; 1997). In western Australia, *Chamaecytisus* *proliferus* hedges grown on a large scale are browsed by cattle (Wiley and Seymour, 2000) and have the added advantage of lowering the water tables and thereby reducing risks of salinization.

**Integrated crop and livestock production can reduce social conflict between nomadic herdsmen and sedentary farmers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | +1 to +3 | L | Especially important in dry Africa |

Small-scale livestock producers, especially nomadic herdsmen, follow broad production objectives that are driven more by immediate needs than by the demands of a market (Ayalew et al., 2001). Conflicts between nomadic herdsmen and sedentary farmers have occurred for thousands of years. Nomadic herdsmen in the Sahel have the right during the dry season to allow their herds to graze in areas where sedentary farmers grow crops in the wet season. This leads to the loss of woody vegetation with consequent land degradation, reduced opportunities for gathering natural products (including dry season fodder), and to lowering of the sustainability of traditional farming practices. The development of living fences/hedges to protect valuable food crops and regenerating trees has the potential to enhance production for the sedentary farmers, but unless the nomads need for continued access to wells, watering holes and dry season fodder is also planned at a regional scale, may lead to worsened conflict (Leakey et al., 1999; Leakey, 2003) In this situation, effective integration of crop and livestock systems has to make provision for alternative sources of dry season fodder (e.g. fodder banks), and corridors to watering holes and grazing lands. Participatory approaches to decision making can avoid such conflicts between sedentary and nomadic herdsmen (Steppler and Nair, 1987; Bruce, 1998; UN CCD, 1998; Blay et al., 2004).

*3.2.2.1.6 Agroforestry and mixed cropping*

Agroforestry practices are numerous and diverse and used by 1.2 billion people (World Bank, 2004a), while tree products are important for the livelihoods of about 1.5 billion people in developing countries (Leakey and Sanchez, 1997) with many of the benefits arising from local marketing (Shackleton et al., 2007). The area under agroforestry worldwide has not been determined, but is known for a few countries (Table 3.3). In Africa trees are typically dominant in agriculture in the areas where they are a major component of the natural vegetation (Fauvet, 1996). Agroforestry practices include many forms of traditional agriculture common prior to colonization; complex multistrata agroforests developed by indigenous peoples in the last one hundred years, scattered trees in pastoral systems, cash crops such as cocoa/tea/coffee under shade, intercropping, improved fallows, and many more (Nair, 1989). As a consequence, while the number of trees in forests is declining, the number of trees on farm is increasing (FAO, 2005e). Agroforestry is the integration of trees within farming systems and landscapes that diversifies and sustains production with social, economic and environmental benefits (ICRAF, 1997). Agroforestry is therefore a practical means of implementing many forms of integrated land management, especially for small-scale producers, which builds on local traditions and practices.

**[Insert Table 3.3]**

**Increased population pressure has resulted in sustainable shifting cultivation systems being replaced by less sustainable approaches to farming.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | A | -5 to +1 | G | Small-scale agriculture |

Throughout the tropics, shifting (swidden) agriculture was the traditional approach to farming with a long forest fallow, representing a form of sequential agroforestry. It was sustainable until increasing population pressure resulted in the adoption of slash-and-burn systems with increasingly shorter periods of fallow. These have depleted carbon stocks in soils and in biomass, and lower soil fertility (Palm *et al*., 2005b), resulting in a decline in crop productivity. In the worst-case scenario, the forest is replaced by farmland that becomes so infertile that staple food crops fail. Farmers in these areas become locked in a “Poverty trap” unable to afford the fertilizer and other inputs to restore soil fertility (Sanchez, 2002).

**Small-scale farmers in the tropics often protect trees producing traditionally important products (food, medicines, etc.) on their farms when land is cleared for agriculture.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S | A | +1 to +3 | G | Mainly small-scale agriculture |

Throughout the tropics, reduced cycles of shifting cultivation with shorter periods of fallow deplete soil fertility resulting in unsustainable use of the land, loss of forest and other adverse environmental impacts. However, trees of traditionally important species have often been saved within new field systems. These trees are sometimes sacred trees, but many are protected or planted as a source of products that were originally gathered from the wild to meet the needs of local people. Now, despite the often total loss of forest in agricultural areas, these same species are commonly found in field systems, often in about a 50:50 mix with introduced species from other parts of the world (Schreckenberg et al., 2002, 2006; Kindt et al., 2004; Akinnifesi et al., 2006). A recent study in three continents has identified a number of more sedentary and sustainable alternative farming systems (Palm et al., 2005b; Tomich et al., 2005; Vosti et al., 2005). These take two forms: one practiced at the forest margin is an enrichment of the natural fallow with commercial valuable species that create an ‘agroforest’ (Michon and de Foresta, 1999), while the second is the integration of trees into mixed cropping on formerly cleared land (Holmgren et al., 1994). It has long been recognized that deforestation of primary forest is a typical response to human population growth, but now it is additionally recognized (Shepherd and Brown, 1998) that after the removal of natural forest, there is an increase in tree populations as farmers integrate trees into their farming systems (Shepherd and Brown, 1998; Michon and de Foresta, 1999; Place and Otsuka, 2000; Schreckenberg et al., 2002; Kindt et al, 2004;) to create new agroforests. This counter intuitive relationship, found in east and west Africa (Holmgren et al., 1994; Kindt et al., 2004), the Sahel (Polgreen, 2007), and southeast Asia (Michon and de Foresta, 1999), seems to be partly a response to labor availability, partly domestic demand for traditional forest products or for marketable cash crops and partly risk aversion (Shepherd and Brown, 1998). Typically these trees are more common in small farms, e.g. in Cameroon, tree density was inversely related to area in farms ranging from 0.7-6.0 ha (Degrande et al., 2006). Accumulation curves of species diversity have revealed that a given area of land had a greater abundance and diversity of trees when it was composed of a greater number of small farms (Kindt et al., 2004). Interestingly, tree density can also be greater in urban areas than in the surrounding countryside (Last et al., 1976).

**The increase in tree planting is partly due to the uptake of cash crops by small-scale farmers as large-scale commercial plantations decline.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | +2 to +4 | R | Mainly small-scale agriculture |

The dynamics of cash-cropping is changing, with small-scale farmers increasingly becoming more commercialized and growing cash crops formerly grown exclusively by estates in mixed systems. This gives them opportunities to reduce their risks by commercializing their cropping systems and income, and expand their income generation, making their farms more lucrative (Vosti et al., 2005). In Indonesia, many small-scale farmers now grow ‘jungle rubber’, producing 25% of world rubber. These farmers can be classified as falling between the two extremes of being completely dependent on wage labor, and completely self-sufficient (Vosti et al., 2005).

**The search for alternatives to slash-and-burn led to the identification of sites where farmers have independently developed complex agroforests.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | 0 to +5 | R | Small-scale agriculture |

In Indonesia, when the food crops are abandoned after 2-3 years, a commercial agroforest develops which provides a continuous stream of marketable tree products (e.g. dammar resin, rubber, cinnamon, fruit, medicines, etc). There are about 3 million ha of these agroforests in Indonesia (Palm *et al*., 2005ab), which have been developed by farmers since the beginning of the last century (Michon and de Foresta, 1996) to replace unproductive forest fallows. These highly productive agroforests are biologically diverse, provide a good source of income, sequester carbon and methane, protect soils, maintain soil fertility and generate social benefits from the land (Palm et al., 2005ab), as well as providing other environmental services. Similar processes are occurring in many places around the world (e.g. the cocoa agroforests of Cameroon, the Highlands of Kenya, the uplands of the Philippines, and Amazonia). In the case of Cameroon, indigenous fruit and nut trees are commonly grown to provide marketable products in addition to the environmental service of shade for the cocoa (Leakey and Tchoundjeu, 2001). Interestingly, in parallel with these developments, farmers have also initiated their own processes of domesticating the indigenous fruits and nuts of traditional importance (Leakey et al., 2004). From the above examples, it is clear that traditional land use has often been effective in combining forest and cropping benefits. In many places, farmers have independently applied their own knowledge to their changing circumstances – situations which arose from such factors as deforestation, the intensification of agriculture, declining availability of land, and changes in land ownership.

**There are many wild species in natural ecosystems that have traditionally been collected and gathered from natural ecosystems to meet the day-to-day needs of people.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | +1 to +4 | G | All but the harshest environments |

For millennia, people throughout the tropics, as hunter-gatherers, relied on the forest as a source of non-timber forest products (NTFPs) for all their needs, such as food, medicines, building materials, artifacts (Abbiw, 1990; de Beer and McDermott, 1996; Falconer, 1990, Villachica, 1996; Cunningham, 2001). NTFPs are still of great importance to communities worldwide (Alexiades and Shanley, 2005; Kusters and Belcher, 2004; Sunderland and Ndoye, 2004). With enhanced marketing they have the potential to support forest community livelihoods and increase the commercial of natural forests, thus strengthening initiatives to promote the conservation of forests and woodlands, especially in the tropics. NTFPs can bee rich in major nutrients, minor nutrients, vitamins and minerals (Leakey, 1999a) and have the potential to provide future products for the benefit of humankind. However, future innovations based on NFTPs must recognize Traditional Knowledge, community practice/law/regulations and be subject to Access and Benefit Sharing Agreements, in accordance with the Convention on Biological Diversity (Marshall et al., 2006).

**Non-timber forest products (NTFP) formerly gathered as extractive resources from natural forests are increasingly being grown in small-scale farming systems, and have become recognized as farm produce (Agroforestry Tree Products – AFTPs**).

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S | A | +1 to +3 | R | Relevant worldwide |

Small-scale farming systems commonly include both exotic and native tree species (Schreckenberg et al., 2002, 2006; Shackleton et al., 2002; Kindt et al., 2004; Degrande et al., 2006) producing a wide range of different wood and non-wood products. Such products include traditional foods and medicines, gums, fibers, resins, extractives like rubber, and timber, which are increasingly being marketed in local, regional and international markets (Ndoye et al., 1997; Awono et al., 2002). These recent developments are generating livelihoods benefits for local communities **(**Degrande et al., 2006) in ways that require little investment of cash and have low labor demands. The term AFTP distinguishes these from extractive NTFP resources so that their role in food and nutritional security and in the enhancement of the livelihoods of poor farmers can be recognized in agricultural statistics (Simons and Leakey, 2004).

**In the last 10 years there has been increasing investment in agroforestry programs to domesticate species producing AFTPs as new cash crops for income generation by small-scale farmers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | Early adoption phase | M-L | Especially relevant to wet / dry tropics |

Socially- and commercially-important herbaceous and woody species are now being domesticated as new crops to meet the needs of local people for traditional foods, medicines, other products (Okafor, 1980, Smartt and Haq, 1997, Guarino, 1997; Schippers and Budd, 1997; Sunderland et al., 1999; Schippers, 2000), and for expanded trade (Ndoye et al., 1997). Participatory domestication of AFTPs is in the early phases of adoption, especially in Africa (Tchoundjeu et al., 2006), small-scale farmers recognize the importance of producing and trading these traditional food species for domestic and wider use and the enhancement of food sovereignty. These programs are improving livelihoods at the household level (Schreckenberg et al., 2002; Degrande et al., 2006), and increasing food and nutritional security. Many of these new crops are important as sources of feed for livestock (Bonkoungou et al., 1998), potential new markets, e.g. vegetable oils (Kapseu et al., 2002) and pharmaceuticals or nutriceuticals (Mander et al., 1996; Mander, 1998), for helping farmers meet specific income needs, e.g. school fees and uniforms (Schreckenberg et al., 2002), and for buffering the effects of price fluctuations in cocoa and other commodity crops (Gockowski and Dury, 1999). This emerging market orientation needs to be developed carefully as it potentially conflicts with community-oriented values and traditions. A series of "Winners and Losers" projects on the commercialization of NTFPs (now Agroforestry Tree Products – AFTPs) have examined these options (e.g. Leakey et al., 2005a; Marshall et al., 2006). These systems target the restoration of natural capital, the wellbeing of the resource-poor farmer and combine ecological benefits with cash generation (Leakey et al., 2005a), making them a component of a 'Localization' strategy. The integration of domesticated indigenous fruit and nut trees into cocoa agroforests would further improve a land use system that is already one of the most profitable and biologically diverse systems (Figure 3.7).

**[Insert Figure 3.7]**

**Domesticated agroforestry trees are producing products that meet many of the needs of small-scale farmers and have the capacity to produce new agricultural commodities and generate new industries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L | B | +2 to +3 | L | Mainly small-scale agriculture |

Participatory rural appraisal approaches to priority setting species selected for domestication found that indigenous fruits and nuts were the species most commonly identified by rural communities (Franzel et al., 1996). Many of these fruits and nuts are important traditional foods with market potential. However, some are also sources of edible oils which are needed for cooking and livestock feed but are deficient in many tropical countries (FAO, 2003b). In West Africa, edible oils are extracted from the fruits/kernels of *Allanblackia* spp. (Tchoundjeu et al., 2006), *Irvingia gabonensis* (Leakey, 1999a), *Dacryodes edulis* (Kapseu et al., 2002), *Vitellaria* *paradoxa* (Boffa et al., 1996) and many other agroforestry species (Leakey, 1999a). Unilever is investing in a new edible oil industry in West Africa, using *Allanblackia* kernel oil (Attipoe et al., 2006). Many agroforestry trees are also good sources of animal fodder, especially in the dry season when pasture is unavailable, and can be grown as hedges, which can be regularly harvested or even grazed by livestock. Opportunities for cattle cake exist from by-products of species producing edible fruits and nuts (e.g. *Dacryodes edulis*, *Canarium indicum*, *Barringtonia procera*, etc.). The nuts of *Croton megalocarpus* are good poultry feed (Thijssen, 2006). In Brazil, new agricultural commodities from agroforestry systems are being used in the manufacture of innovative products for the automobile industry (Panik, 1998).

**Twenty-five years of agroforestry research have developed techniques and strategies to assist farmers to reverse soil nitrogen depletion without the application of fertilizers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | A | +2 to +4 | M-L | Mainly small-scale agriculture |

Leguminous trees fix atmospheric nitrogen through symbiotic associations with soil microorganisms in root nodules (Sprent and Sprent, 1990; Sprent, 2001). The soil improving benefits of this process can be captured in ways that both improve crop yield and are easily adopted by resource-poor farmers (Buresh and Cooper, 1999), conferring major food security benefits to these farming households. Some techniques, such as alley-cropping/hedgerow intercropping are of limited adoptability because of the labor demands, while others such as short-term improved fallows are both effective and adoptable (Kwesiga et al., 1999; Franzel, 1999). Short-term improved fallows in Africa involving species such as *Sesbania sesban*, *Gliricidia sepium*, and *Tephrosia vogelii*, accumulate 100-200kg N $ha^{-1}$ in 6-24 months and to raise maize yields from about 0.5 to 4-6 tonnes $ha^{-1}$ (Cooper, et al., 1996). An external source of phosphorus in needed for active N fixation in many P-deficient tropical soils.

**Tree/crop interactions are complex but can be managed for positive outcomes**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | A | -2 to +3 | M-L | Many situations |

There are many different types of competitive interactions between trees and crops in mixed farming systems, which can be evaluated on the basis of the Land Equivalent Ratio. After 25 years of intensive study the complex physiological and ecological impacts of tree/crop interactions are now well understood (Ong and Huxley, 1996; Huxley, 1999; van Noordwijk et al., 2004); there is much evidence of the overall productivity (biomass) of agroforestry systems being greater than annual cropping systems, due to the capture of more light and water, and improved soil fertility (Ong and Huxley, 1996). Ultimately, however, it is the economic and social outcomes of beneficial interactions that usually determine the adoption of agroforestry systems (Franzel and Scherr, 2002). The numerous examples of agroforestry adoption indicate that farmers, especially small-scale farmers, recognize that the benefits are real.

**Vegetated riparian buffer strips are planted for bioremediation of herbicide and nitrate pollution**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, E | B | +2 to +3 | L | Temperate and tropical agriculture |

Vegetated buffer strips have been shown to retain >50% of sediment within the first few meters (Young et al.,1980; Dillaha et al.,1989; Magette et al.,1989; Mickelson et al., 2003). The planting of trees in strategically important parts of the catchment to maximize water capture and minimize run-off is one of the generally recognized ways of conserving water resources (Schultz et al., 1995, 2000; Louette, 2000; Lin et al., 2003, 2005). In the corn belt of the US, agroforestry strips (trees planted in grass strips) on the contour in a corn/soybean rotation had decreased loss of total P by 17% and loss of nitrate N by 37% after three years (Udawatta et al., 2004). This minimization of nutrient loss is one of the most important environmental services performed by agroforestry trees (van Noordwijk et al., 2004). Among several possible management practices, a tree-shrub-grass buffer placed either in upland fields (Louette, 2000) or in riparian areas (Schultz et al., 1995, 2000) is recognized as a cost effective approach to alleviating non-point sources of agricultural pollutants transported from crop land. Herbicide retention by buffers can also be substantial (Lowrance et al., 1997; Arora et al., 2003).

**Enhanced agroecological function is promoted by agroforestry.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | +1 to +3 | M-L | Especially in the tropics |

Agroecological function is dependent on the maintenance of biological diversity above and below ground, especially the keystone species at each trophic level. The ways in which biodiversity stimulates the mechanisms and ecological processes associated with enhanced agroecological function are poorly understood in any crop (Collins and Qualset, 1999); nevertheless, based on numerous studies, the principles are well recognized (Altieri, 1989; Gliessman, 1998) and are based on those of natural ecosystems (Ewel, 1999). Through the integration of trees in farming systems, agroforestry encourages and hastens the development of an agroecological succession (Leakey, 1996; Schroth et al., 2004), which creates niches for colonization by a wide range of other organisms, above and below-ground, in field systems (Ewel, 1999; Leakey, 1999b; Schroth et al., 2004; Schroth and Harvey, 2007). Integrating trees encourages and enhances agroecological function, providing enhanced sustainability as a result of active life cycles, food chains, nutrient cycling, pollination, etc. at all trophic levels, and helping to control pests, diseases, and weeds (Collins and Qualset, 1999) in about two thirds of the agroforests tested (Schroth et al., 2000), Agroforestry is thus capable of rehabilitating degraded farmland.

Agroforestry systems support biodiversity conservation in human-dominated landscapes in the tropics (Schroth and Harvey, 2007), through reducing the conversion of primary habitat and providing protective ecological synergies; providing secondary habitat; and by offering a more benign matrix for “islands” of primary habitat in the agricultural landscape, especially by buffering forest edges and creating biological corridors which provide maintenance of meta-population structure (Perfecto and Armbrecht, 2003). Scaling up successful agroforestry approaches requires both improving livelihood and biodiversity impacts at the plot scale, and strategic placement within a landscape mosaic to provide ecosystem services (e.g. watershed protection, wildlife habitat connectivity).

**Agroforestry strategies and techniques have been developed for the rehabilitation of degraded agroecosystems and the reduction of poverty particularly in Africa.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| 1, 2, 3, 4, 5, 6 | A | +1 to +4 | M-L | Wide applicability, especially in tropics |

Agroforestry has evolved from an agronomic practice for the provision of environmental services, especially soil fertility amelioration, to a means of enhancing agroecological function through the development of an agroecological succession involving indigenous trees producing marketable products (Leakey, 1996). In this way it now integrates environmental and social services with improved economic outputs (Leakey, 2001ab). At the community level, agroforestry can positively affect food security andthe livelihoods of small-scale farmers. It can also reverse environmental degradation by providing simple biological approaches to soil fertility management (Young, 1997; Sanchez, 2002); generating income from tree crops (Degrande et al., 2006); minimizing risk by diversifying farming systems (Leakey, 1999b) and; restoring agroecosystem services (Sanchez and Leakey, 1997). Consequently, agroforestry has been recognized as an especially appropriate alternative development strategy for Africa (Leakey, 2001 ab), where the Green Revolution has had only modest success (Evenson and Gollin, 2003).

**Agroforestry can mitigate anthropogenic trace gas emissions through better soil fertility and land management, and through carbon sequestration**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | +1 to +2 | L | Small number of studies in the tropics |

The integration of trees in cropping systems can improve soil organic matter, nutrient cycling and the efficient use of water, reduce erosion and store carbon due to improved plant growth. Early assessments of national and global terrestrial $CO_2$ sinks reveal two primary benefits of agroforestry systems: direct near-term C storage (decades to centuries) in trees and soils, and, potential to offset immediate greenhouse gas emissions associated with deforestation and shifting agriculture. Within the tropical latitudes, it is estimated that one hectare of sustainable agroforestry can potentially offset 5–20 ha of deforestation. On a global scale, agroforestry systems could potentially be established on $585–1275 \times 10^6$ ha of technically suitable land, and these systems could store 12–228 (median 95) tonnes C $ha^{-1}$ under current climate and soil conditions (Dixon, 1995). Landscape-scale management holds significant potential for reducing off-site consequences of agriculture (Tilman et al., 2002), leading to integrated natural resources management (Sayer and Campbell, 2001) (see 3.2.2.2.4).

**Mixed farming systems, such as those involving cereal/legume mixtures can increase productivity and sustainability of intensive systems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | +1 to +3 | R | Especially important in Asia |

African savanna has a short growing season (4-5 months) with annual precipitation of 300-1300 mm. In these areas farmers typically grow maize, millet, sorghum, soybean, groundnut, and cowpea, often integrated with livestock production. Traditionally, the sustainability of intensive cereal-based systems in Asia was due to the presence of green manuring practices for soil fertility management and retention of below-ground biodiversity. However, increasing land prices and wage rates had made this option economically unviable at least in the short term and the use of green manures has declined substantially (Ali, 1998). Now short-duration grain legume varieties are available that can be incorporated in the cereal-based intensive systems (Ali et al., 1997). These grain legumes have enhanced farmers' income in the short term and improved cropping system productivity and sustainability in the long-term (Ali and Narciso, 1996). Mixed cropping also has the benefit of reducing pest infestations and diseases.

*3.2.2.1.8 Watershed management*

Watersheds are often mosaics that integrate many different land uses; when denuded they are very vulnerable to degradation, with severe downstream consequences in terms of flooding, landslides, siltation and reduced water quality (CA, 2007). Additionally, surface water tends to pass through deforested watersheds more quickly leaving towns and villages more susceptible to water shortages. Water storage schemes to supply urban populations and industrial complexes, or for irrigation schemes, can be wasteful and create conflicts between different water users.

**Environmental sustainability of water resources is greatest when people work with natural systems and processes, rather than against them.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | 0 to +4 | R | Wide applicability |

The most successful watershed management schemes involve participation of local communities. For example, there are traditional user-managed, water catchment and management projects in many parts of the world (e.g., in southern India, the mountainous regions of the Andes, Nepal, and upland South East Asia), which are more sustainable than those imposed by hierarchical water authorities. Schemes involving local communities tend to use water more sustainably (Ruf, 2001; Molle, 2003) than modern schemes, .For example, by 2001 the Syr and Amu Dar'ya rivers shrunk to less than half their size in 1957, due to intensive irrigation of cotton and rice in the former Soviet Union(UNEP, 2002).

**The Lake Victoria Basin project is an integrated watershed approach to assessing the biophysical and socioeconomic effects of environmental degradation.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | 0 to +2 | N | Widespread applicability |

Lake Victoria, the world's second largest lake (68,000km$^2$), is located in an agricultural area with high population density (28 million people on 116,000 km$^2$ of farm land). It displays multiple water degradation problems associated with high river sediment loads from erodible soil, and unsustainable farming practices such as intense cultivation and nutrient depletion. The local communities have serious and wide-scale socioeconomic problems as a result of low crop productivity. The Lake Victoria Basin project has used an integrated water shed approach involving participatory monitoring and evaluation, coupled with spectral reflectance and remote sensing, to characterize the problems and develop agroforestry interventions and livestock exclusion trials to promote more environmentally sustainable farming practices (Swallow *et al*., 2002).

*3.2.2.1.9 Organic systems and biointensive agriculture*

Organic agriculture, includes both certified and uncertified production systems that encompass practices that promote environmental quality and ecosystem functionality. Organic agriculture is based on minimizing the use of synthetic inputs for soil fertility and pest management. From a consumer viewpoint, this is valuable for avoiding the perceived health risks posed by pesticide residues, growth-stimulating substances, genetically modified organisms and livestock diseases. There are also environmental benefits associated with organic production practices that arise from lower levels of pesticide and nutrient pollution in waterways and groundwater (FAO/WHO, 1999).

**Organic agriculture is a small industry (1-2% of global food sales) but it has a high market share in certain products and is a fast growing global food sector.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | A | +1 to +2 | G | Niche marketing worldwide |

Although global food sales are minimal (1-2%), there are some products with a substantial market; in Germany organic milk products have >10% market share and organic ingredients in baby food comprise 80 to 90% of market share. In the USA, organic coffee accounts for 5% of the market although it is only 0.2% worldwide (Vieira, 2001). The total market value of organic products worldwide, reached US $27.8 billion in 2004. There has been annual market growth of 20-30% (growth in the overall food production sector is 4-5% per year) (ftp://ftp.fao.org/paia/organicag/2005_12_doc04.pdf).

**Food labeled as organic or certified organic is governed by a set of rules and limits, usually enforced by inspection and certification mechanisms known as guarantee systems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, E, S, D | A | +1 to +3 | G | Wide applicability |

There has been a steady rise in the area under organic agriculture. With very few exceptions, synthetic pesticides, mineral fertilizers, synthetic preservatives, pharmaceuticals, sewage sludge, GMOs, and irradiation are prohibited in organic standards. Sixty industrialized countries currently have national organic standards; there are hundreds of private organic standards worldwide (FAO/ITC/CTA. 2001; IFOAM, 2003, 2006). Regulatory systems for organics usually consist of producers, inspection bodies, an accreditation body for approval and system supervision and a labeling body. There are numerous informal regulatory systems outside of formal organic certification and marketing systems (peer or participatory models) that do not involve third-party inspection and often focus on local markets. The harmonization of organic standards is an issue in international trade. Harmonization has been facilitated by the organic agriculture global umbrella body, the International Federation of Organic Agriculture Movements (IFOAM) and through CODEX guidelines. The CODEX guidelines concern the production process and provide consumer and producer protection from misleading claims and guide governments in setting standards (FAO/WHO, 1999; El-Hage Scialabba, 2005). The extent of non-certified systems is difficult to estimate, particularly in developing countries.

**Worldwide, more than 31 million ha of farmland were under certified organic management in 2006.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, E, S | A | +1 to +3 | G | Worldwide applicability |

Globally organic production covers 31 million ha on more than 600,000 farms in approximately 120 countries. Organic production is rapidly expanding with an aggregate increase of 5 million hectares from 2005 to 2006. Australia has the largest area of land under organic certification systems (12.2 million ha), but Latin America has the greatest total number of organic farms (Willer and Yussefi, 2006). By region, most of the world's certified organic land is in Australia / Oceania (39%), Europe (21%), Latin America (20%), and Asia (13%). In Switzerland, more than 10% of all agricultural land is managed organically. Large areas, particularly in developing countries and some former Soviet States, are organic by default (i.e. non-certified), as farmers cannot afford to purchase fertilizers and pesticides (Willer and Yussefi, 2006). The extent of such non-market organic agriculture is difficult to quantify, but >33% of West African agricultural production comes from non-certified organic systems (Anobah, 2000). In Cuba which has made substantial investments in research and extension, organic systems produce 65% of the rice, 46% of fresh vegetables, 38% of non-citrus fruit, 13% of roots, tubers and plantains and 6% of the eggs (Murphy, 2000).

**Yields in organic agriculture are typically 10-30% lower than those with conventional management, but in many cases organic systems are economically competitive.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | B | -1 to +3 | R | Widespread applicability |

Yield reductions are commonly associated with adoption of organic practices in intensive production systems (Mäder et al., 2002; Badgley et al., 2007). While yields may be 10-30% lower, profits are, on average, comparable to those on conventional farms. Pest and fertility problems are particularly common during transitions to organic production. As with all production systems, the yield penalty associated with organic agriculture depends on farmer expertise with organic production methods and with factors such as inherent soil fertility (Bruinsma, 2003). In contrast to the reduced productivity responses observed in many high-yielding systems, traditional systems converted to organic agriculture, yields typically do not fall and may increase (ETC/KIOF, 1998).

**Organic agriculture greatly reduces or eliminates the use of synthetic agents for pest control.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, E | A | -2 to +3 | G | Widespread |

The use of synthetic agrochemicals, the foundation of modern agriculture, has been linked to negative impacts such as ground and surface water contamination (Barbash et al., 1999; USGS, 2006), harm to wildlife (Hayes et al., 2002), and acute poisoning of agricultural workers, particularly in the developing world where protection standards and safety equipment are often inadequate (Repetto and Baliga, 1996). Organic systems greatly reduce or eliminate synthetic pesticide use (Mäder et al., 2002), thereby diminishing these concerns. However, a small minority of the pest control substances allowed under organic standards (e.g. copper for downy mildew control in viticulture) also pose human and environmental health risks. Also, the lower efficacy of some organic pest control methods contributes to the yield penalty associated with organic systems. In the longer term, increased biodiversity and an increase in predator species can contribute to a more balanced agroecosystem.

**Enhanced use of organic fertility sources can improve soil quality and sustain production, but in some situations supplies of these sources can be inadequate for sustaining high-yielding organic production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, E | A | -2 to +3 | G | Widespread |

Adequate soil organic matter are vital for maintaining soil quality; it is a source of macro and micronutrients for plant nutrition, enhances cation exchange capacity and nutrient retention, and facilitates aggregation and good soil structure. However, shortages of organic soil amendments are common in many developing regions (e.g. Mowo et al., 2006; Vanlauwe and Giller, 2006), especially where high population density and cropping intensity preclude rotations with N-fixing legumes or improved fallows and there are competing uses for animal manures (e.g. for cooking fuel). When population pressure is high or environments are degraded some of the most common organic resources available to farmers (e.g. cereal stovers) are of poor quality, with low nutrient concentrations and macronutrient ratios not commensurate with plant needs. Modern best practice guidelines for conventional production systems advise the full use of all indigenous fertility sources (composts, crop residues, and animal manures), with mineral fertilizers employed to bridge deficits between crop needs and indigenous supplies (e.g. http://www.knowledgebank.irri.org/ssnm/)

**Some facets of organic agriculture have clear benefits for environmental sustainability; evidence for others is mixed, neutral, or inconclusive.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | A, C | -2 to +4 | G | Wide applicability |

Since organic agriculture is more clearly defined by what it prohibits (e.g. synthetics) than what it requires, the environmental benefits that accrue from organic production are difficult to generalize. Some evidence suggests that above and below-ground biodiversity is higher in organic systems (Bengtsson et al., 2005; Mäder et al., 2006), but neutral outcomes are also reported from long-term experiments (e.g. Franke-Snyder et al., 2001); species richness sometimes increases among a few organisms groups while others are unaffected (Bengtsson et al., 2005). Biodiversity impacts from organic agriculture are influenced by factors such as crop rotation and tillage practices, quantity and quality of organic amendments applied to the soil, and the characteristics of the surrounding landscape. Although some studies demonstrate reduced environmental losses of nitrate N in organic systems (e.g. Kramer et al., 2006), most evidence suggests that nitrate losses are not reduced in high-yielding organic systems when contrasted to conventional production system (Kirchmann and Bergstroem, 2001; DeNeve et al., 2003; Torstensson et al., 2006). While fossil energy consumption can be substantially reduced in organic systems, energy savings must be balanced against productivity reductions (Dalgaard et al., 2001). For organic systems with substantially lower yields than conventional alternatives, total enterprise energy efficiency (energy output per unit energy input) can be lower than the efficiency of conventional systems (Loges et al., 2006).

**Organic markets are mostly in industrialized countries but organic markets, with a comparative advanatage are emerging in developing countries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | B | +1 to +2 | G | Worldwide applicability |

Although the highest market growth for organic produce is in North America, the highest reported domestic market growth (approx. 30%) is in China; organic is also increasing in Indonesia. The range of marketing approaches is diverse and includes organic bazaars, small retail shops, supermarkets, multilevel direct selling schemes, community supported agriculture and internet marketing (FAO/ITC/CTA, 2001; IFOAM, 2006; Willer and Yussefi, 2006). The low external input production systems found in many developing countries are more easily converted to certified organic systems than to high external intensive production systems. Organic tropical and sub-tropical products such as coffee, tea, cocoa, spices, sugar cane and tropical fruits transition more easily to organic since they are generally low external input systems. The higher labor requirements of organic farming provide a comparative advantage to developing countries with relatively low labor costs (de Haen, 1999).

**There are significant constraints for developing countries to the profitable production, processing and marketing of organic products for export**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | B | -1 to -3 | R | Developing economies |

Organic markets require high quality produce and the added costs and complexities of certification. This is a constraint for developing countries where market access may be difficult due to limited and unreliable infrastructure and a lack of skilled labor. Evidence suggests that the current price premium for organic produce will decline in the long term as supply rises to meet demand and as larger corporate producers and retailers enter the market. A lower price premium may make organic agriculture uneconomical for many small-scale producers in developing countries with poor rural infrastructure and services (de Haen, 1999). However, these constraints provide an opportunity for industrialized countries to assist developing countries to expand value-adding skills and infrastructure.

**Organic demand is increasingly driven by big retailers with brands that dictate standards.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, D | A | -3 to +3 | G | Negative in poor and positive in rich countries |

Large and vertically coordinated supermarket chains now account for a major share of the retail markets for fresh and processed organic foods. Supermarket sales of organic produce range from 40% in Germany, 49% in USA, to 80% in Argentina and the UK, and 85% in Denmark. Most large food companies have acquired organic brands and small firms, initiated partnerships with organic companies, or have their own organic lines. Mergers and acquisitions of organic brands and companies affect production, processing, certification and distribution pathways, e.g in California, 2% of organic growers represent 50% of organic sales. The world's largest organic food distributor has sales of US $3.5 billion. Increasing domination of the organic market by big companies may control market access, and lead to price regulation that reduces returns to farmers. This trend could potentially undermine one of the central principles of organic agriculture: providing a better return to farmers to support the costs of sustainable production. Industry concentration is leading to pressure to erode organic standards (El-Hage Scialabba, 2005). There may however be other benefits to some producers such as ease and scale of marketing and more standardized production.

**The localization of marketing has some benefits for small-scale organic producers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, D | A | +1 to +3 | M-L | Small-scale producers and traders |

Some initiatives (organic farmers markets, box home delivery and community supported agriculture) have successfully empowered small-scale farmers and promoted localized food systems by supporting community-based, short food supply chains in domestic markets Generally these initiatives are small in scale but seen in total and as a global trend in industrialized and developing countries their impact is significant. One example of larger scale success is a farm in Denmark that delivered 22, 000 organic boxes per week (annual sales of Euros 20 million) in 2005. Other innovations to promote the localization of organic production are the facilitation of dialogue between different government Ministries (e.g. agriculture, trade, environment, rural development, education, health, tourism) and civil society operators (e.g. farmer associations, inspectors, accreditors, traders, retailers, consumers) and location-specific research and knowledge sharing through Organic Farmers-Field-Schools to promote location-specific research and knowledge sharing (El-Hage Scialabba, 2005).

3.2.2.2 Managing agricultural land for ecosystem services and public goods

Agroecosystems are increasingly recognized as potential providers of ecosystem services, yet typically cultivated land has lower biodiversity than natural ecosystems, and is frequently associated with reduced ecosystem services (Cassman et al., 2005), consequently necessitating tradeoffs between production and ecosystem services.

*3.2.2.2.1 Water quality and quantity*

The available global freshwater resource has been estimated at 200000 $km^3$ (Gleick, 1993; Shiklomanov, 1999), of which over 90% is groundwater (Boswinkel, 2000). Population growth has reduced annual *per capita* water availability from 12,900$m^3$ in 1970 to less than 7,800$m^3$ in 2000 (CA, 2007). With water a scarce resource, the role of agriculture in wise water resource management is increasing in importantance (CA, 2007). Currently, 7,200 $km^3$ of water are used in crop production annually and this is predicted to double by 2050 (IWMI, 2006). There are two major trends in water management - government intervention on large scale projects (Molden et al., 2007b), and private and community investments in small scale projects (e.g. 26 million private small scale irrigation pumps owners in India). Large dams, reservoirs and irrigation systems are typically built by government agencies, which often continued to operate them for economic development (including agriculture, urbanization, power generation), without adequate consideration of farmer needs.

**Present trends in irrigation water management within public and private sector have significant positive and negative effects on environment.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -2 to +3 | G | Worldwide |

Rainfall contributes about 110,000 $km^3$ of water per year worldwide, 40% enters rivers and groundwater (43,500 $km^3$) (Molden et al., 2007a). The rapid increase of irrigation in the last 50 years (Figure 3.1c) has led to dramatic modifications of hydrological systems around the world with the diversion of water from natural aquatic ecosystems (2700 $km^3$) for irrigation having well documented negative environmental effects (Richter et al., 1997; Revenga et al., 2000; WCD, 2000; MA, 2005ab; Falkenmark et al., 2007). These include salinization (20-30 million ha – Tanji and Kielen, 2004), river channel erosion, loss of biodiversity, introduction of invasive alien species, reduction of water quality, genetic isolation through habitat fragmentation, and reduced production of floodplain and other inland/coastal fisheries. Conversely, water management practices have also contributed to environmental sustainability, with the development of irrigation reducing the amount of land required for agriculture. In recent years irrigation and water storage have also been found to create new habitats for water birds in Asia, leading to population increase (Galbraith, et al., 2005). Thus the co-existence of wetlands and agriculture for 10,000 years has influenced many ecological modifications (Bambaradiniya and Amerasinghe, 2004), but now the balance tends to be negative.

**Improved water management can lead to more equitable water use, but this is not common**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | -2 to +3 | G | Wide applicability |

Access to water is critical for poverty reduction with large positive impacts on agricultural productivity when combined with equitable distribution (Merrey et al., 2007). Targeted investments in water management in both rainfed and irrigated areas can effectively reduce inequity by providing more opportunities for the poor (Castillo et al., 2007). In China equity tends to increase with agricultural water management, because crops grown on irrigated land have the highest effect on lowering inequality (Huang et al., 2005). Equity in irrigation and agricultural water management are increased by equitable land distribution, secure ownership or tenancy rights, efficient input, credit, and product markets; access to information; and nondiscriminatory policies for small-scale producers and landless laborers (Smith, 2004; Hussain, 2005), but these conditions are rarely met and inequity occurs if wealthy and powerful people gain preferential access to water (Cernea, 2003). Interventions often exacerbate the existing imbalance between men and women's water ownership rights, division of labor and incomes (Ahlers, 2000; Boelens and Zwarteveen, 2002; Chancellor, 2000). The poorest farmers are often those at the end of irrigation systems because they receive less water and have the lowest certainty about the timing and amount delivered.

**Improved water management can lead to efficient water use.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | 0 to +3 | G | Wide applicability |

Better water management can result in gains in water productivity, better management of rainfed agriculture, improvements in stakeholder management of schemes and reduced evaporation. In low-yielding rainfed areas and in poorly performing irrigation systems, improved water productivity can be achieved by more reliable and precise application of irrigation water, improved soil fertility and improved soil conservation practices. Improving water productivity – gaining more yield per unit of water – is an effective means of intensifying agricultural production and reducing environmental degradation (Molden et al., 2007b). Increased agricultural productivity can also occur when women's land and water rights are strengthened and there is gender sensitivity in the targeting of credit and input provision, training, and market linkages, especially in areas where women are the farm decision makers (Quisumbing, 1995; van Koppen, 2002). However, gains in water productivity are often overstated as much of the potential has already been met in highly productive systems; a water productivity gain by one user can be a loss to another, e.g., upstream gains in agriculture may be offset by a loss in downstream fisheries, either through increased extraction or agrochemical pollution.

**Water user groups are emerging as the key social tool to meet the needs of different communities.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | B | +1 to +3 | R | Wide applicability |

Access to water is critical for poverty reduction (Molden et al., 2007b). However, poor farmers often have poor access to water, as their traditional systems of water rights are overlooked by water management agencies. Smaller-scale community investments in water projects can allow better access to adequate and better quality water. One way of managing water delivery is the establishment of Water User Associations (Abernethy, 2003), but communities of water users face numerous challenges in gaining equitable and sustainable access to, and allocations of, water (Bruns and Meinzen-Dick, 2000; Meinzen-Dick and Pradhan, 2002). Social reforms to improve the equity of water allocation include providing secure water rights for users and reducing or eliminating water subsidies. Acknowledging customary laws and informal institutions can facilitate and encourage local management of water and other natural resources (CA, 2007). Clarifying water rights can ensure secure access to water for agriculture for poor women and men and other disadvantaged groups, such as the disabled (CA, 2007; IFAD, 2006) and ensure better operations and maintenance. The management of water resources can be further improved through training and capacity development. The benefits of farmer-managed irrigation schemes were confirmed in a worldwide study of 40 irrigation schemes (Tang, 1992), and a study of over 100 irrigation systems in Nepal (Lam, 1998). Management of water at the local level has to be part of an integrated process: basin, regional, national and sometimes trans-boundary (CA, 2007).

**Structurally complex land use systems can enhance hydrological processes and provide some relief from water scarcity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B, E | +1 to +2 | R | Large land masses |

On a regional scale, the capacity of vegetation to trap moisture and to return it to the atmosphere by surface evaporation and transpiration affects hydrological processes and hence the distribution of rainfall (Salati and Vose, 1984). Regional-scale advection of atmospheric moisture is adversely affected by removal of woody vegetation (natural and crops), because of greater water losses to surface runoff, groundwater and a reduction of evaporation and transpiration from the canopy (Salati and Vose, 1984; Rowntree, 1988; Shuttleworth, 1988). Thus the maintenance of perennial vegetation has positive effects on rainfall patterns that enhance hydrological processes (Meher-Homji, 1988) affecting the amount of moisture that can be advected downwind to fall as rain somewhere else (Salati and Vose, 1984). Mixed perennial agricultural systems can probably mimic these hydrological functions of natural forests (Leakey, 1996).

**Estuarine habitats are the interface between terrestrial freshwater and marine environments. They are important nursery grounds for the production of commercially important marine fishes, but are subject to detrimental agricultural, urban and industrial developments.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E | B | -1 to +3 | R | Worldwide applicability |

Qualitative evidence of the use of estuarine habitats by juvenile marine fishes is plentiful (Pihl et al., 2002), but recent quantitative research, including stable isotope analysis and otolith chemistry (Hobson, 1999; Gillanders et al., 2003), has confirmed and emphasized the importance of river estuaries in the connectivity between freshwater and marine habitats (Gillanders, 2005; Herzka, 2005; Leakey, 2006). While few marine fish species are considered to be dependent on estuaries, substantial energetic subsidies to fish populations are derived from their juvenile years living and feeding in estuaries (Leakey, 2006). Given the continued vulnerability of estuaries to the loss of water quality from degradation, pollution and other detrimental human impacts, information about the behavior and resource use of juvenile fishes is crucial for future fisheries management and conservation (Leakey, 2006). In the tropics, mangrove swamps are particularly important (Mumby et al., 2004).

*3.2.2.2.2 Conserving biodiversity (in situ, ex situ) and ecoagriculture*

Biodiversity is the total variation found within living organisms and the ecological complexes they inhabit (Wilson, 1992) and is recognized as a critical component of farming systems above and below ground (Cassman et al., 2005; MA, 2005c). It is important because there are many undomesticated species that are currently either under-utilized, or not yet recognized as having value in production systems. Secondly, terrestrial and aquatic ecosystems contain many species crucial to the effective functioning of food-chains and life-cycles, and which consequently confer ecological sustainability or resilience (e.g. regulation of population size, nutrient-cycling, pest and disease control). The conservation of genetic diversity is important because evolutionary processes are necessary to allow species to survive by adapting to changing environments. Crop domestication, like this evolution requires a full set of genes and, thus, is grounded in intra-specific genetic diversity (Harlan, 1975; Waliyar et al., 2003).

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**Biological diversity plays a key role in the provision of agroecological function.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | A | -3 to +4 | G | General principle |

Ecological processes affected by agroecosystem biodiversity , include pollination, seed dispersal, pest and disease management, carbon sequestration and climate regulation (Diaz et al., 2005; MA, 2005c). Wild pollinators are essential to the reproduction of many crops, especially fruits and vegetables (Gemmill-Herren et al., 2007). To maintain a full suite of pollinators and increase agricultural productivity, requires the protection of the habitats for pollinators (forests, hedgerows, etc.) within the agricultural landscape. A number of emerging management approaches to diversified agriculture (ecoagriculture, agroforestry, organic agriculture, conservation agriculture, etc.) seek to preserve and promote biodiversity (described above in 3.2.2.1).

**The conservation of biological diversity is important because it benefits humanity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -4 to +4 | G | Worldwide |

Humans have exploited plant diversity to meet their everyday needs for food, medicine, etc. for millennia. Agrobiodiversity is increasingly recognized as a tangible, economic resource directly equivalent to a country's mineral wealth. These genetic resources (communities, species and genes) are used by breeders for the development of domesticated crops and livestock (IPGRI, 1993). Species and ecosystems can be conserved for their intrinsic qualities (McNeely and Guruswamy, 1998), but biodiversity conservation is increasingly recognized for its importance in combating malnutrition, ill health, poverty and environmental degradation. Collecting and conserving the world's germplasm in gene banks has been estimated at US $5.3 billion (Hawkes et al., 2000), but the cost is greatly outweighed by the value of plant genetic resources to the pharmaceutical, botanical medicine, major crop, horticultural, crop protection, biotechnology, cosmetics and personal care products industries (US $500 - 800 billion per year) (ten Kate and Laird, 1999).

**Agrobiodiversity is threatened.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -4 to 0 | G | Worldwide problem |

Agrobiodiversity is rapidly declining due to the destruction and fragmentation of natural ecosystems, over-exploitation, introduction of exotic species, human socioeconomic changes, human instigated and natural calamities, and especially changes in agricultural practices and land use, notably the replacement of traditional crop varieties with modern, more uniform varieties. Nearly 34,000 species (12.5% of the world's flora) are currently threatened with extinction (Walters and Gillett, 1998), while 75% of the genetic diversity of agricultural crops has been lost since the beginning of the last century (FAO, 1998a). On 98% of the cultivated area of the Philippines, thousands of rice landraces have been replaced by two modern varieties, while in Mexico and Guatemala, *Zea mexicana* (teosinte), the closest relative of maize has disappeared. The loss of endangered food crop relatives has been valued at about US $10 billion annually (Phillips and Meilleur, 1998).

**There are two major conservation strategies:*ex situ* and *in situ*.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | 0 to +5 | G | Widely applicable |

The Convention on Biological Diversity (CBD, 1992) defines *ex situ conservation* as the conservation of components of biological diversity outside their natural habitats and *in situ conservation* as the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings. In an ideal world It would be preferable to conserve all diversity naturally (*in situ*), rather than move it into an artificial environment (*ex situ*). However, *ex situ* conservation techniques are necessary where *in situ* conservation cannot guarantee long-term security for a particular crop or wild species. In both cases, conservation aims to maintain the full diversity of living organisms; *in situ* conservation also protects the habitats and the interrelationships between organisms and their environment (Spellerberg and Hardes, 1992). In the agrobiodiversity context, the explicit focus is on conserving the full range of genetic variation within taxa (Maxted et al., 1997). The two conservation strategies are composed of a range of techniques (Table 3.4) that are complementary (Maxted et al., 1997).

**[Insert Table 3.4]**

**Ecoagriculture is an approach to agricultural landscape management that seeks to simultaneously achieve production, livelihoods and wildlife/ecosystem conservation.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | 0 to +4 | G | Worldwide applicability |

The Ecoagriculture Initiative secures land as protected areas for wildlife habitat in recognition that these areas may need to be cleared for future agriculture (McNeely and Scherr, 2003; Buck et al., 2004). A set of six production approaches have been proposed: (i) creating biodiversity reserves that benefit local farming communities, (ii) developing habitat networks in non-farmed areas, (iii) reducing land conversion to agriculture by increasing farm productivity, (iv) minimizing agricultural pollution, (v) modifying management of soil, water and vegetation resources, (vi) modifying farm systems to mimic natural ecosystems (McNeely and Scherr, 2003). A review of the feasibility of integrating production and conservation concluded that there are many cases of biodiversity-friendly agriculture (Buck et al., 2004; 2007), both for crop and livestock production (Neely and Hatfield, 2007). Nevertheless, economic considerations involving issues of valuation and payment for ecosystems services, as well as building a bridge between agriculturalists and conservation scientists remain a major challenge.

**Modern molecular techniques for assessing and understanding the structure of wild genetic resources have greatly enhanced crop and animal breeding programs.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | B | +1 to +4 | G | Relevant worldwide |

Over the last 20 years, a range of molecular marker techniques (Table 3.2) have informed plant genetic resource management activities (Newton et al., 1999: Lowe et al., 2004). These techniques have revolutionized genetics by allowing the quantification of variations in the genetic code of nuclear and organellar genomes, in ways which give high quality information, are reproducible, easily scored, easily automated, and include bioinformatics handling steps. These techniques involve universal primers that can be used across a range of plant, animal and microbial taxonomic groups, avoiding the need for individual development. They also provide unequivocal measures of allele frequencies; distinguish homozygotes and heterozygotes and allow rapid identifications of gene fragments using different DNA sequences (Lowe et al., 2004).

**Molecular techniques are contributing to different approaches of surveying and assessing genetic variation for management and conservation purposes.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | A | +1 to +4 | G | Relevant worldwide |

Assessments of population genetic structure using molecular techniques (Table 3.2) have involved the following approaches: (i) surveys of a species to identify genetic hot spots (e.g. Lowe et al., 2000), genetic discontinuities (Moritz, 1994), genetically isolated and unique populations (Cavers et al., 2003) or populations under different geopolitical management that need to be uniformly managed for the conservation of the species (Karl and Bowen, 1999; Cavers et al., 2003); (ii) identification of the genetic history of domesticated species to construct a history of introduction and likely sources of origin (Zerega et al., 2004, 2005), and weed invasions including the search for biological control agents from a relevant source region (McCauley et al., 2003); (iii) examination of remnant populations of an exploited or depleted species to assess future population viability and develop appropriate management actions and determine processes and ecological factors affecting gene flow dynamics, and (iv) development of genetic resource management strategies for plants in the early stages of domestication by comparisons of exploited and non-exploited populations or between domesticated and natural populations.

**Domestication can lead to reduced genetic diversity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | A | -4 to +1 | G | Relevant worldwide |

The loss of genetic diversity can arise from processes associated with domestication: i) competition for land resources resulting from the widespread planting of domesticated varieties may lead to the elimination of natural populations, ii) pollen or seed flow from cultivars in production areas can overwhelm those of remnant wild populations, causing genetic erosion of the natural populations (Hardner et al., 2007), iii) a genetic bottleneck is formed when selective breeding of one or a few superior lines (e.g. *Inga edulis* - Hollingsworth et al 2005; Dawson et al., 2007) results in increased inbreeding or increased genetic differentiation relative to source populations. Consequently domesticated lines often contain only a subset of the genetic variation of natural populations. Conversely, however, the breeding process can also be used to fix extreme traits or introduce additional variation in selected phenotypic characters. Agricultural diversity depends on wild sources of genes from neglected and underutilized species in order to maintain the productivity and adaptability of domesticated species. The optimization of livelihood benefits during environment change requires a stronger integration between initiatives to conserve agricultural biodiversity and wild biodiversity (Thompson et al., 2007).

**Domesticated populations can have conservation value.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | B | 0 to +3 | R | Relevant worldwide |

Recent studies using molecular techniques have found that when domestication occurs in ways that do not lead to the loss of wild populations, genetic erosion or genetic bottlenecks, the domesticated population can itself provide a valuable contribution to genetic resource management and conservation. In Latin America, *Inga edulis*, which has been utilized by local people for several thousands of years (Dawson et al., 2007), has remained genetically diverse in five sites in the Peruvian Amazon relative to natural stands (Hollingsworth et al., 2005). In this example, genetic differentiation estimates indicated that the domesticated stands were introduced from remote sources rather than from proximate natural stands (Dawson et al., 2007). Despite maintaining high levels of diversity, this suggests that domesticated stands can also have negative impacts on long term performance through source mixing.

**Village-level domestication strategies have conservation advantages in the context of global genetic resource management.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E | D | 0 to +3 | R | Relevant worldwide |

Village-level domestication has been promoted for the development of new tree crops in developing countries (Weber et al., 2001; Leakey et al., 2003), rather than the centralized distribution of a single line or a few selected genotypes. This practice involves individual communities or villages developing superior lines of new crops from local populations or land races that are specific to the participating communities, using established domestication practices. This strategy has the inherent advantage of harnessing adaptive variation for a range of local environmental factors, while sourcing from multiple villages ensures that a broad range of genetic variation is preserved across the species range. This strategy provides long-term benefit for genetic diversity conservation where native habitats are increasingly being lost to development. The success of this strategy lies partly in developing an appreciation for a diversity of forms within the new crop, such as has occurred in the wine industry, where customers have been educated to appreciate the diversity of flavors offered by different grape varieties.

**Biodiversity and genetic diversity have been 'protected' by international policies.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | Expected to be positive | G | Worldwide |

The Convention on Biological Diversity (CBD, 1992) was ratified in 1993 to address the broad issues of biodiversity conservation, sustainable use of its components and the equitable sharing of the benefits arising from the use of biodiversity. Its Global Strategy of Plant Conservation (GSPC) included global targets for 2010, such as "*70% of the genetic diversity of crops and other major socioeconomically valuable plant species conserved.*" The International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2002a) specifically focuses on agrobiodiversity conservation and sustainable use. The imperative to address current threats to genetic diversity was recognized by the Conference of the Parties (www.cbd.int/2010-target) to the CBD 2010 Biodiversity Target, which committed the parties "*to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth*." Thus it is recognized that the international, regional and national level conservation and sustainable use of agrobiodiversity is fundamental for future wealth creation and food security.

*3.2.2.2.3 Global warming potential, carbon sequestration and the impacts of climate change.*

The combustion of fossil fuels, land use change, and agricultural activities constitute the dominant sources of radiatively-active gas emissions (i.e. greenhouse gases - GHG) since the advent of the industrial revolution. Expressed in $CO_2$ equivalents (i.e. greenhouse warming potential -

GWP), agriculture now accounts for approximately 10-12% of net GWP emissions to the atmosphere from anthropogenic sources (IPCC, 2007; Smith et al., 2007), excluding emissions from the manufacture of agrochemicals and fuel use for farm practices. The IPCC also reports that nearly equal amounts of $CO_2$ are assimilated and released by agricultural systems, resulting in an annual flux that is roughly in balance on a global basis. In contrast, agriculture is a significant net source of the important greenhouse gases methane ($CH_4$ ) and nitrous oxide ($N_2O$), contributing approximately 58% and 47% of all emissions, respectively (Smith et al., 2007).

Agriculture affects the radiative forcing potential of the atmosphere (Greenhouse Warming Potential - GWP) in various ways, including: (i) heat emission from burnings of forests, crop residues and pastureland (Fearnside, 2000); (ii) carbon dioxide emissions from the energy-intensive processes required to produce agricultural amendments like nitrogen fertilizers, pesticides, etc. (USEPA, 2006), (iii) greater sensible heat fluxes from bare soils (Foley et al., 2003), (iv) infrared radiation from bare soil (Schmetz et al., 2005) and reduced evapotranspiration from soils without vegetative cover; (v) decreased surface albedo (i.e. sunlight reflectance) when plant residues are burned (Randerson et al., 2006); (vi) soil organic matter oxidation promoted by tillage (Reicosky, 1997); (vii) methane emissions from ruminant livestock (Johnson and Johnson, 1995) and wetland rice cultivation (Minami and Neue, 1994) and (viii) nitrous oxide emissions (Smith et al., 1997) from poorly drained soils, especially under conditions where N fertilizers are misused. In aggregate, agriculture is responsible for approximately 15% of anthropogenic $CO_2$ emissions, 58% of methane ($CH_4$) emissions and 47% of $N_2O$ (Smith et al., 2007).

**Agroecosystems can also be net sinks for atmospheric GWP. Best agricultural practices help to minimize emissions of greenhouse gases.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | A | -3 to +3 | G | Especially important in the tropics |

In addition to being a source of greenhouse gas emissions, certain agricultural practices found to increase the “sink” value of agroecosystems include: (i) maintaining good aeration and drainage of soils to reduce $CH_4$ and $N_2O$ emissions, (ii) maximizing the efficiency of N fertilizer use to limit $N_2O$ emissions (Dixon, 1995) and to reduce the amount of $CO_2$ released in the energy-intensive process of its manufacture, (iv) minimizing residue burning to reduce $CO_2$ and $O_3$ emissions, and (v) improving forage quality to reduce $CH_4$ and $N_2O$ emissions from ruminant digestion (Nicholson et al., 2001), (vi) maximizing woody biomass and (vii) avoiding burning that promotes ozone formation which is photochemically active with OH radicals; OH radicals remove atmospheric $CH_4$ (Crutzen and Zimmerman, 1991; Chatfield, 2004).

**Recent studies on wheat, soybean and rice in Free-Air Concentration Enrichment (FACE) field experiments suggest that yield increases due to enhanced $CO_2$ are approximately half that previously predicted.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E, S | B | -2 to +2 | R | Wide applicability |

Free-Air Concentration Enrichment (FACE) experiments fumigate plants with enhanced $CO_2$ concentrations in open air field conditions (Ainsworth and Long, 2005). Yield stimulation of major $C_3$ crops in elevated [$CO_2$] is approximately half of what was predicted by early experiments in enclosed chambers (Kimball et al., 1983; Long et al., 2006), casting doubt on the current assumption that elevated [$CO_2$] will offset the negative effects of rising temperature and drought, and sustain global food supply (Gitay et al., 2001). Notably the temperate FACE experiments indicate that: (i) the $CO_2$ fertilization effect may be small without additions of N fertilizers (Ainsworth and Long, 2005), and (ii) harvest index is lower at elevated [$CO_2$] in soybean (Morgan et al., 2005) and rice (Kim et al., 2003).

**Crop responses to elevated to $CO_2$ vary depending on the photosynthetic pathway the species uses.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, E, S | B | -3 to +3 | R | Variation between crop species |

Wheat, rice and soybean are crops in which photosynthesis is directly stimulated by elevated $CO_2$ (Long et al., 2004). When grown at 550 ppm $CO_2$ (the concentration projected for 2050), yields increased by 13, 9 and 19% for wheat, rice and soybean, respectively (Long *et al.,* 2006). In contrast, photosynthetic pathways in maize and sorghum are not directly stimulated by elevated $CO_2$; these crops do not show an increase in yield when grown with adequate water supply in the field at elevated $CO_2$ (Ottman et al., 2001; Wall et al., 2001; Leakey et al., 2004, 2006). At elevated $CO_2$, there is an amelioration of drought stress due to reduced water use, hence yields of maize, sorghum and similar crops might benefit from elevated $CO_2$ under drought stress.

**Soil-based carbon sequestration (CS) can provide a significant, but finite sink for atmospheric $CO_2$.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | +2 to +4 | G | Worldwide |

In recognition that social and economic factors ultimately govern the sustained adoption of land-based CS, strategies have been sought that sequester carbon while providing tangible production benefits to farmers (Ponce-Hernandez et al., 2004). For arable systems, no-till cultivation has been promoted as a "win-win" strategy for achieving net Global Warming Potential (GWP) reductions. Tillage disrupts soil aggregates, making organic matter pools that had been physically protected from microbial degradation more vulnerable to decomposition (Duxbury, 2005). Higher levels of soil organic matter are associated with attributes, such as crop tilth, water holding capacity and fertility that are favorable to crop growth (e.g. Lal, 1997). Although concerns have been raised about the methodologies used to assess soil carbon stocks (Baker et al., 2007), recent synthesis of data from many sites across the United States suggests that adoption of no-till

(West and Post, 2002) or conversion of cropland into perennial pastures (Post and Kwon, 2000) generates soil organic carbon increases on the order of 450 kg C $ha^{-1}$ $yr^{-1}$. Depending on factors such as soil texture and land use history, maximum rates of C sequestration tend to peak 5-10 yrs after adoption of CS practices and slow markedly within two decades. Hence increasing the organic matter content of soils is as an interim measure for sequestering atmospheric $CO_2$. Estimates from the United States suggest that if all US cropland was converted to no-till, enhanced CS rates would compensate for slightly less than 4% of the annual $CO_2$ emissions from fossil fuels in the U.S. (Jackson and Schlesinger, 2004). On a global scale, carbon sequestration in soils has the potential to offset from 5 to 15% of the total annual $CO_2$ emissions from fossil fuel combustion in the near-term (Lal, 2004).

**Improved management of the vast land area in rangelands has led to significant carbon sequestration, but the benefits of carbon credit payments are not currently accessible, particularly in common property systems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | B | 0 to +3 | R | Wide applicability |

Grazing lands cover 32 million $km^2$, and sequester large quantities of carbon (UNDP/UNEP/WB/WRI, 2000). Processes that reduce carbon sinks in grazing lands include overgrazing, soil degradation, soil and wind erosion, biomass burning, land onversion to cropland; carbon can be improved by shifting species mixes, grazing and degradation management, fire management, fertilization, tree planting (agroforestry), and irrigation (Ojima et al., 1993; Fisher et al., 1994; Paustian et al., 1998). But where land is held in common, mitigation is particularly complex. Mitigation activities are most successful when they build on traditional pastoral institutions and knowledge (excellent communication, strong understanding of ecosystem goods and services) and provide pastoral people with food security benefits at the same time (Reid et al., 2004).

**Agroecosystems involving tree-based carbon sequestration can offset greenhouse gas emissions.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | 0 to +4 | G | Wide applicability |

Early assessments of national and global terrestrial $CO_2$ sinks reveal two primary benefits of agroforestry systems: direct near-term C storage (decades to centuries) in trees and soils, and, potential to offset immediate greenhouse gas emissions associated with deforestation and shifting agriculture. On a global scale, agroforestry systems could potentially be established on 585–1275 $10^6$ ha, and these systems could store 12–228 (median 95) tonnes C $ha^{-1}$ under current climate and soil conditions (Dixon, 1995). In the tropics, within 20-25 years the rehabilitation of degraded farming systems through the development of tree-based farming systems could result in above-ground carbon sequestration from 5 tonnes C $ha^{-1}$ for coffee to 60 tonnes C $ha^{-1}$ for complex agroforestry systems (Palm et al., 2005a). Below-ground carbon sequestration is generally lower, with an upper limit of about 1.3 tonnes C $ha^{-1}$ $yr^{-1}$ (Palm et al., 2005a). Agroforestry systems with nitrogen-fixing tree species, which are of particular importance in degraded landscapes, may be associated with elevated $N_2O$ emissions (Dick et al., 2006). The benefits of tree-based carbon sequestration can have an environmental cost in terms of some soil modification (Jackson et al., 2005) (see 3.2.2.1.7).

**The value of increased carbon sequestration in agroecosystems (e.g. from no-till) must be judged against the full lifecycle impact of CS practices on net greenhouse warming potential (GWP).**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | -2 to +2 | R | Temperate zone |

Increased CS is not the only GWP-related change induced by adoption of agronomic practices like no-till. No-till maize systems can be associated with comparatively large emissions of $N_2O$ (Smith and Conen, 2004; Duxbury, 2005). Over a 100-yr timeframe, $N_2O$ is 310 times more potent in terms of GWP than $CO_2$ (Majumdar, 2003) and higher $N_2O$ emissions from no-till systems may negate the GWP benefits derived from increased rates of carbon sequestration. On the other hand, soil structural regeneration and improved drainage may eventually result in a fewer $N_2O$ emissions in no-till systems. Nitrogen fertilization is often the surest method for increasing organic matter stocks in degraded agroecosystems, but the benefits of building organic matter with N fertilizer use must be discounted against the substantial $CO_2$ emissions generated in the production of the N fertilizer. By calculating the full lifecycle cost of nitrogen fertilizer, many of the gains in CS resulting from N fertilization are negated by $CO_2$ released in the production, distribution, and application of the fertilizer (Schlesinger, 1999; Follett, 2001; West and Marland, 2002).

**Climate change is affecting crop-pest relations.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | 0 to -3 | G | Worldwide |

Climate change results in new pest introductions and hence changes in pest-predator-parasite population dynamics as habitat changes (Warren et al., 2001; McLaughlin et al., 2002; Menendez et al., 2006; Prior and Halstead, 2006; UCSUSA, 2007). These changes result from changes in growth and developmental rates, the number of generations per year, the severity and density of populations, the pest virulence to a host plant, or the susceptibility of the host to the pest and affect the ecology of pests, their evolution and virulence. Similarly, population dynamics of insect vectors of disease, and the ability of parasitoids to regulate pest populations, can change (FAO, 2005a), as found in a study across a broad climate gradient from southern Canada to Brazil (Stireman et al., 2004). Changing weather patterns also increase crop vulnerability to pests and weeds, thus decreasing yields and increasing pesticide applications (Rosenzweig, 2001; FAO, 2005a). Modeling can predict some of these changes (Oberhauser and Townsend

Peterson, 2003) as well as consequences hence aiding in the development of improved plant protection measures, such as early warning and rapid response to potential quarantine pests. Better information exchange mitigate the negative effects of global warming. However, the impacts of climate change are not uni-directional; there can be benefits.

**There is evidence that changes in climate and climate variability are affecting pest and disease distribution and prevalence.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | 0 to –3 | R | Worldwide |

Pests and diseases are strongly influenced by seasonal weather patterns and changes in climate, as are crops and biological control agents of pests and diseases (Stireman et al., 2004; FAO, 2005a). Established pests may become more prevalent due to favorable growing conditions such as include higher winter temperatures and increased rainfall. In the UK the last decade has been warmer than average and species have become established that were seen rarely before, such as the vine weevil and red mites ` with potentially damaging economic consequences (Prior and Halstead, 2006). Temperature increase may influence crop pathogen interactions and plant diseases by speeding up pathogen growth rates (FAO, 2005a). Climate change may also have negative effects on pests.

**Livestock holdings are sensitive to climate change, especially drought.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | -1 to -3 | R | Especially in dry tropics |

Climate fluctuation is expected to threaten livestock holders in numerous ways (Fafchamps et al., 1996; Rasmussen, 2003). Animals are very sensitive to heat stress; require a reliable resource of drinking water, and pasture is sensitive to drought. In addition, climate change can affect the distribution and range of insect vectors of human and livestock diseases, species like mosquitoes (malaria, encephalitis, dengue), ticks (tick typhus, lyme disease), tsetse fly (sleeping sickness). These infectious and vector-borne animal diseases have increased in important worldwide and disease emergencies are occurring with increasing frequency (FAO, 2005a; Oden et al., 2006; Jenkins et al., 2006). These problems are thought to be furthers exacerbated by climate change because hunger, thirst and heat-stress, increase susceptibility to diseases. Small-scale farmers do not have the resources to take appropriate action to minimize these risks.

**The Kyoto Protocol has recognized that Land Use, Land Use Change and Forestry (LULUCF) activities can play a substantial role in meeting the ultimate policy objective of the UN Framework Convention on Climate Change.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | 0 to +3 | G | Wide applicability |

LULUCF activities are ‘carbon sinks’ as they capture and store carbon from the atmosphere through photosynthesis, conservation of existing carbon pools (e.g. avoiding deforestation), substitution of fossil fuel energy by use of modem biomass, and sequestration by increasing the size of carbon pools (e.g. afforestation and reforestation or an increased wood products pool). The most significant sink activities of UNFCCC (www.unfccc.int) are the reduction of deforestation, and the promotion of tree planting, as well as forest, agricultural, and rangeland management.

*3.2.2.2.4 Energy to and from agricultural systems - bioenergy*

Bioenergy has recently received considerable public attention. Rising costs of fossil fuels, concerns about energy security, increased awareness of global warming, domestic agricultural interests and potentially positive effects for economic development contribute to its appeal to policy makers and private investors. However, the costs and benefits of bioenergy depend critically on local circumstances and are not always well understood (see also Chap 4, 6, 7).

**Biomass resources are one of the world's largest sources of potentially sustainable energy, comprising about 220 billion dry tonnes of annual primary production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | 0 to +2 | G | Wide applicability |

World biomass resources correspond to approximately 4,500 EJ (Exajoules) per year of which, however, only a small part can be exploited commercially. In total, bioenergy provides about 44 EJ (11%) of the world's primary energy consumption (World Bank, 2003). The use of bioenergy is especially high (30% of primary energy consumption) in low-income countries and the share is highest (57%) in sub-Saharan Africa, where some of the poorest countries derive more than 90% of their total energy from traditional biomass. Also within developing countries the use of bioenergy is heavily skewed towards the lowest income groups and rural areas. In contrast, modern bioenergy, such as the efficient use of solid, liquid or gaseous biomass for the production of heat, electricity or transport fuels, which is characterized by high versatility, efficiency and relatively low levels of pollution, accounts for 2.3% of the world's primary share of energy (FAO, 2000b; IEA, 2002; Bailis, et al. 2005; Kartha, et al., 2005).

**Traditional bioenergy is associated with considerable social, environmental and economic costs,**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | A | -3 to +2 | G | Especially in the tropics |

The energy efficiency of traditional biomass fuels (e.g. woodfuels) is low, putting considerable strain on environmental biomass resources, which are also important sources of fodder and green manure for soil fertility restoration as well as other ecosystem services. Inefficient biomass combustion is also a key contributor to air pollution in the homestead leading to 1.5 million premature deaths per year (WHO, 2006). Collecting fuelwood is time-consuming, reducing the time that people can devote to productive activities each day *e.g.* farming and education (UNDP, 2000; IEA, 2002; Goldemberg and Coelho, 2004; Karekezi, et al., 2004; World Bank, 2004b; Bailis, et al., 2005).

**Production of modern liquid biofuels for transportation, predominantly from agricultural crops, has grown rapidly (25% per year) in recent years, spurred by concerns about fossil energy security and global warming and pressures from agricultural interest groups.**

| GOALS E | CERTAINTY B | RANGE OF IMPACTS 0 to +3 | SCALE G | SPECIFICITY Wide applicability |
|---|---|---|---|---|

Modern liquid biofuels, such as bioethanol and biodiesel contributed only about 1% of the total road transport fuel demand worldwide in 2005 (IEA, 2006c). The main 1st generation products are ethanol and biodiesel. Ethanol is produced from plant-derived starch (e.g. sugar cane, sugar beet, maize, cassava, sweet sorghum), primarily in Brazil (16,500 million liters) and the US (16,230 million liters). In 2005, world production was over 40,100 million liters (Renewable Fuels Association, 2005). Sugar cane derived ethanol meets about 22% of Brazil's gasoline demand (Worldwatch Institute, 2006), much of it used in flexfuel vehicles, which can operate under different gasoline-ethanol blends (e.g. 10% ethanol: 90% gasoline). In terms of vehicle fuel economy, one liter of ethanol is equivalent to about 0.8 liters of gasoline – accounting for its lower energy content but higher octane value (Kojima and Johnson, 2005). Biodiesel is typically produced chemically from vegetable oils (e.g. rapeseed, soybeans, palm oil, *Jatropha* seeds) by trans-esterification to form methyl esters. Germany was the world's biggest producer (1,920 million liters) in 2005, followed by other European countries and the USA. Biodiesel production has been growing rapidly (80% in 2005) but overall production levels are an order of magnitude smaller than ethanol (REN 21, 2006). Biodiesel contains only about 91% as much energy as conventional diesel, and can be used in conventional diesel engines, either pure or blended with diesel oil (EPA, 2002). Other biofuels such as methanol and butanol only play a marginal role in markets today but may become more important in the future.

**The production of liquid biofuels for transport is rarely economically sustainable.**

| GOALS E | CERTAINTY C, E | RANGE OF IMPACTS Not yet known | SCALE G | SPECIFICITY Mainly in developed countries |
|---|---|---|---|---|

The economic competitiveness of biofuels is widely debated and depends critically on local market conditions and production methods. The main factors determining biofuels competitiveness are (i) the cost of feedstock, which typically contributes about 60-80% of total production costs (Berg, 2004; Kojima and Johnson, 2005), (ii) the value of byproducts (e.g. glycerin for biodiesel and high fructose maize syrup for maize ethanol), (iii) the technology that determines the scale of the production facility, the type of feedstock and conversion efficiency, and (iv) the delivered price of gasoline or diesel. Brazil is widely recognized to be the world's most competitive ethanol producer from sugar cane, with 2004-2005 production costs of US $0.22-0.41 per liter of gasoline equivalent (*versus* US $0.45-0.85 per liter in USA and Europe), but the world price of sugar and the exchange rate of the Brazilian currency determine price competitiveness. Brazilian ethanol production can be competitive with oil prices at about US $40-50 per barrel (*versus* about US $65 per barrel in Europe and USA, if one takes agricultural subsidies into account). It is estimated that oil prices in the range of US $66-115 per barrel would be needed for biodiesel to be competitive on a large scale. In remote regions and land-locked countries, where exceptionally high transport costs add to the delivered price of gasoline and diesel, the economics may be more favorable but more research is needed to assess this potential (IEA, 2004ab; Australian Government Biofuels Task Force, 2005; European Commission, 2005; Henke et al., 2005; Kojima and Johnson, 2005; Henninges and Zeddies, 2006; Hill, et al., 2006; IEA, 2006c; OECD, 2006a; Worldwatch Institute, 2006; Kojima, et al., 2007). In order to promote production despite these high costs biofuels are most often subsidized (see Chap 6.3.4).

**Bioelectricity and bioheat are produced mostly from biomass wastes and residues.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | 0 to +2 | G | Wide applicability |

Both small-scale biomass digesters and larger-scale industrial applications have expanded in recent decades. The major biomass conversion technologies are thermo-chemical and biological. The thermo-chemical technologies include direct combustion of biomass (either alone or co-fired with fossil fuels) as well as thermo-chemical gasification (to producer gas). Combined heat and power generation (cogeneration) is more energy efficient and has been expanding in many countries, especially from sugarcane bagasse (Martinot et al., 2002; FAO, 2004b; REN 21, 2005; IEA, 2006a; DTI, 2006). The biological technologies include anaerobic digestion of biomass to yield biogas (a mixture primarily of methane and carbon dioxide). Household-scale biomass digesters that operate with local organic wastes like animal manure can generate energy for cooking, heating and lighting in rural homes and are widespread in China, India and Nepal. However their operation can sometimes pose technical as well as resource challenges. Industrial-scale units are less prone to technical problems and increasingly widespread in some developing countries, especially in. China. Similar technologies are also employed in industrial countries, mostly to capture environmentally problematic methane emissions (e.g. at landfills and livestock holdings) and produce energy (Balce, et al., 2003; Ghosh, et al., 2006; IEA, 2006b). Despite the fact that production costs can be competitive in various settings, in the past many attempts to promote wider distribution of modernized bioenergy applications have failed. Common problems included technical difficulties and the failure to take into account the needs and priorities of consumers, as well as their technical capabilities, when designing promotion programs (Ezzati and Kammen, 2002; Ghosh, et al., 2006; Kartha, et al., 2005).

**Bioelectricity and bioheat production can be competitive with other sources of energy under certain conditions, especially the combination of heat and power generation within industries producing waste biomass.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | -2 to +3 | G | Wide applicability |

The competitiveness of bioelectricity and bioheat depends on (i) local availability and cost of feedstocks – many of which are traded on market with strong prices variations both regionally and seasonally; (ii) capital costs and generation capacity; (iii) cost of alternative energy sources; and (iv) local capacity to operate and maintain generators. Generally, bioelectricity production is not competitive with grid electricity but generation costs can compete with off-grid option such as diesel generators in various settings. Key to competitiveness is a high capacity utilization to compensate for relatively high capital costs and exploit cheap feedstock costs. High capacity factors can best be reached when proven technologies (e.g. thermo-chemical combustion) are employed 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. Estimates for power generation costs in such facilities range from US $0.06 - 0.12/kWh ( WADE, 2004; REN 21, 2005; World Bank, 2005a; IEA, 2006b). In combined heat and power mode, when capital investments can be shared between electricity and heat generation, electricity generation costs can decrease to US $0.05-0.07/kWh, depending on the value of the heat ( REN 21, 2005; IEA, 2006b). Thermo-chemical gasification can have higher generation costs and low capacity utilization due to weak electricity demand and technical failures caused by improper handling and maintenance can lead to even higher production costs ( Larson, 1993; World Bank, 2005a; Banerjee, 2006; Ghosh, et al., 2006; Nouni, et al., 2007). Data on electricity production costs with anaerobic digesters are not widely available, because most digesters are not installed commercially but through government programs to provide (i) energy access for rural households and villages, often solely for the provision of cooking fuel or heating or (ii) methane capture on environmental grounds (e.g. in several industrialized countries). Overall, the economics of biomass power and heat can be improved through carbon credits.

### *3.2.3. Impacts of AKST on livelihoods, capacity strengthening and empowerment*

#### 3.2.3.1 Methodologies and approaches for assessing impact

Assessing the evidence for the contribution of AKST to improving livelihoods and empowerment is complex. While there is evidence of contribution to increasing productivity of agriculture and sustainability of natural resource use, the extent to which this is relevant to specific groups of people and translates into improved livelihoods, is more complicated, involving differential impacts between and within populations. The difficulty of attribution applies similarly to negative outcomes. The paths of causality are complex and highly contingent on specific conditions (Adato and Meinzen-Dick, 2007), involving interactions between AKST and the policies and institutional contexts in which AKST products are promoted and adopted. Hence the assessments of impacts are sometimes contradictory or controversial. The methodological challenges of impact assessment are considerable; especially when going beyond economic measures of impact or individual case studies. Thus it is difficult to make broader statements on the poverty and livelihood impacts of AKST investments and products across different geographical regions and client groups. Impact assessments rely on comparison – before and after a specific intervention or change, or a ‘with’ and ‘without’ situation (the counterfactual either being empirically measured, or theoretically constructed assuming the best available alternatives are pursued). This approach has been helpful in establishing the economic returns from agricultural research and the contribution of increased productivity, but is more difficult to construct for the livelihood dimensions.

*3.2.3.1.1 Assessment of the economic impacts of AKST*

Past assessments of impacts of specific AKSTs have documented adoption, productivity increases and financial returns and consequences for national food security (Evenson and Gollin, 2003a; Hazell and Ramasamy, 1991). There is evidence that agricultural productivity growth has a substantial impact on poverty reduction, although this is conditional on contextual and socioeconomic conditions, e.g. equitable land distribution (Kerr and Kolavalli, 1999; Hazell and Haddad, 2001; Jayne et al., 2003; Mathur et al., 2003; Thirtle et al., 2003; ). Economists have developed techniques to quantify the total economic value of the multitude of products and services (social/environmental and local/global) from agricultural programs, such as agroforestry (Pearce and Mourato, 2004).

**Impact assessments of investment in agricultural research have shown that it has been highly cost effective.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, D | B | +2 to +4 | G, R, N | Wide applicability |

Investment in research has resulted in substantial economic gains from increased productivity. For example, in the case of the CGIAR system benefit-cost ratios for research have been between 1.94 (significantly demonstrated and empirically attributed) and 17.26 (plausible, extrapolated to 2011) (Raitzer, 2003). Three innovations – MVs of rice (47% of benefits), MVs of wheat (31% of benefits) and cassava mealy bug biocontrol (15% of benefits) account for most of the impact using the most stringent criteria, and are worth an estimated US $30 billion [at 1990 values] (Evenson and Gollin, 2003b; Raitzer, 2003; Hossain et al., 2003; Heisey et al., 2002; Lantican et al., 2005). While focused on a very narrow range of species, as a measure of this success, the CGIAR has estimated that 30 years of agricultural research on seven major crops and three livestock products has improved yield gains so much that, had this gain not occurred, an additional 170-340 million ha of forests and grasslands would have been needed for production (FAO, 2003a, Nelson and Maredia, 1999). Other estimates of forestalled conversion of habitat to agricultural use are as high as 970 million ha (Golkany, 1999). A cost/benefit analysis by ACIAR (Raitzer and Lindner, 2005) found that research projects involving forestry/agroforestry had the greatest benefits (42.9%). Increases in total factor productivity, which contribute to increased output, are always associated with investment in research (Pingali and Heisey, 1999; McNeely and Scherr, 2003). These studies pay less attention to the social and institutional distribution of impacts or to non economic benefits.

*3.2.3.1.2 Assessment of livelihood impacts of AKST*

Systematic and detailed impact assessments of AKST's contribution to livelihood improvement and the sustainability of livelihoods over time are generally lacking. A livelihood is said to be sustainable "when it can cope with and recover from shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base" (Carney, 1998). Indirect impacts of AKST in relation to ownership of assets, employment on and off farm, vulnerability, gender roles, labor requirements, food prices, nutrition and capacity for collective action have been less thoroughly researched than the financial and economic impacts (Meinzen-Dick et al., 2004; Hazell and Haddad, 2001), although, recent impact assessments of Participatory Methods have more comprehensively addressed these issues. Comparative case studies of livelihood change incorporating qualitative dimensions and complementing other methods have begun to document the non-economic impacts of AKST. (*www.prgaprogram.org/modules.php?op=modload&name=Web_Links&file=index&req=viewlink&cid=133&min=0&orderby=titleA&show=10*).

**Livelihoods approaches have usefully contributed to conceptual and methodological innovations.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | 0 to +3 | R, N, L | Wide applicability |

The concept of 'sustainable livelihoods' is both an AKST product and a tool, which facilitates the analysis of livelihood status and changes and the understanding of *ex ante* and *ex post* impacts. The livelihoods framework considers livelihoods as comprising the capabilities, assets and activities required for a means of living. This is a broader and more holistic view than just equating 'livelihood' with income or employment (Booth et al., 1998). It links the notion of sustaining the means of living with the principle of environmental sustainability (Carney, 1998). The elements of the livelihoods framework include the assets that people use and combine to make a living, the factors which cause vulnerability; the policies, institutions and processes which affect the environment for livelihoods; the livelihood strategies followed and the outcomes. The livelihoods framework has been used to assist situational analysis for research and development planning and to assess specific institutional, policy and technology and rural development options prior to intervention (Ashley and Carney, 1999; Shackleton et al., 2003; OECD, 2006b). More recently it has been used to assist evaluation of outcomes and impacts (Ashley and Hussein, 2000; Adato and Meinzen-Dick, 2003; Meinzen-Dick et al., 2004; Adato and Meinzen-Dick, 2007) and has complemented more macro-level economic impact assessments. Livelihoods analysis has been further assisted by the development and refinement of participatory tools for poverty and situational analysis, especially in the context of improving client orientation and gender relevance of agricultural research and development (World Bank, 1998). Recently, the framework has helped to identify principles and processes critical to achieving sustainable livelihoods, and to understand the complexities associated with partnerships to promote local empowerment, resiliency and diversification (Butler and Mazur,2007). Its limitations include the absence of integration of dimensions of power, the unspecified nature of 'institutions and processes' which require further elaboration of knowledge, culture and innovation and the need for further tools to understand the dynamics of livelihood changes.

3.2.3.2 The contribution of AKST to livelihoods improvement

The improvement of livelihoods depends on the accessibility of the products of AKST. This depends on the factors influencing uptake, the distribution of benefits of specific technologies and their impacts. Particular attention is paid to impacts on overall levels of poverty and economic status, human health; natural and physical assets, social relationships, and vulnerability.

*3.2.3.2.1 AKST and poverty*

**Some gains have been made in the reduction of poverty, but the contribution of AKST to increasing agricultural production and agriculture based incomes has been very different in different regions, agroecologies and for different groups of people.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, D | A | -2 to +3 | R, N, L | Incidence of poverty remains high in some African countries |

AKST and agricultural transformation have had an important influence on the economic and social situation of many countries. Poverty is a serious global problem with 3 billion people (2.1 billion are rural poor) earning less than the purchasing power equivalent of US $2/day. The impacts of AKST are location specific and depend on complex interacting factors. Between 1990 and 2002, the proportion of people living in extreme poverty fell more rapidly in much of Asia compared with Africa, Latin America and the Caribbean (UN, 2006a); while in central and eastern Europe, the poverty rates increased. In sub-Saharan Africa, although there was a small decline in the rate of poverty, the number of people living in extreme poverty increased by 140 million. Poor countries (especially in SSA) have gained proportionately less than some richer countries (USA and Europe). Similarly, major benefits have escaped marginal agroecological regions (rain-fed dryland areas) and marginalized people (small-scale farmers, landless people, seasonally mobile populations, women and the poorest) (Fan et al., 2000; Hazell and Haddad, 2001; Sayer and Campbell, 2001). While the Green Revolution yielded large production gains in some commodity crops, basic grains and livestock, it was often at the expense of environmental degradation (Pingali and Rosegrant, 1994). Elsewhere, for example, in Uttar Pradesh and Tamil Nadu in India, it benefited the poor, including some landless laborers, reducing inequality and improving economic opportunities (Hazell and Ramasamy, 1991; Sharma and Poleman, 1993). Intensive agricultural development, particularly in Europe, led to over supply, sanitary problems affecting livestock production and ecological issues, while the concentration of production caused economic and social decline in marginal areas (Hervieu and Viard, 1996).

**Farmers have not always benefited from crop breeding.**

| GOALS<br>N, H, L, S | CERTAINTY<br>B | RANGE OF IMPACTS<br>0 to +3 | SCALE<br>G, R, N, L | SPECIFICITY<br>Widespread |
|---|---|---|---|---|

The initial success of the Green Revolution was a result of its focus on more favorable irrigated rice and wheat systems (Huang et al., 2002), but crop varieties bred for responsiveness to such conditions were less successful when the focus shifted to more marginal and variable environments (Smale et al., 1998; Witcombe et al., 2001). Although the adoption of 'modern' varieties has been widespread (up to 70% in some crops) (Evenson and Gollin 2003a; 2003b), farmers in more marginal areas have not always benefited from the latest research on pest/disease resistance and yield (Witcombe, 1999; Witcombe et al., 2001). Varieties bred on research stations have not always been well adapted to local conditions and preferences; nor for acceptable quality, utility for multipurpose uses; or acceptable post-harvest characteristics (e.g. easy to thresh/process, good taste, good storability). Consequently, comparatively few of the hundreds of rice varieties released in India are grown by farmers (Witcombe et al., 1998) while some traditional varieties, e.g. a peanut variety grown in southern India, remain popular (Bantilan et al., 2003). Some new and potentially better modern varieties have failed to reach farmers due to the inefficiency of the varietal release and seed multiplication system (Witcombe et al., 1988). Participatory approaches can help overcome this inefficiency (Uphoff, 2002).

**Livestock are important for rural livelihoods, but livestock technologies have made only a limited contribution to improving rural livelihoods .**

| GOALS<br>N, H, L, E, S, D | CERTAINTY<br>C | RANGE OF IMPACTS<br>+1 to +3 | SCALE<br>R, N, L | SPECIFICITY<br>New AKST more positive in industrialized countries. |
|---|---|---|---|---|

Livestock are of greater importance to poor people and the landless than those with higher incomes (Delgado et al., 1999). Livestock management in difficult environments is knowledge-intensive and integrated into complex social and natural resource management systems. In general, small-scale farmers have largely relied on traditional and local knowledge to sustain their livestock production systems (Falvey and Chantalakhana, 1999). Of an estimated 600 million livestock keepers globally, most of whom are in mixed rainfed systems, 430 million are resource poor and concentrated in SSA and south Asia (Heffernan et al., 2005). The important developments in livestock technologies (feed technologies in intensive livestock production systems; artificial insemination; embryo transfer etc.) are more widely used in the industrialized world, as there are constraints to applying these technologies in developing countries (Madan, 2005). Thus, the rapid growth in consumption of livestock products in developing countries has been due to increased numbers, rather than increased productivity (Delgado et al., 1999). Vaccination against major animal diseases has been successful in developing countries, e.g. rinderpest in Africa and Newcastle disease in Asia. In Africa, net annual economic benefit attributed to the elimination of rinderpest has been valued at US $1 billion (http://www-naweb.iaea.org/nafa/aph/stories/2005-rinderpest-eradication.html). Likewise, heat stable vaccination against Newcastle disease has led to improved village poultry production in Indonesia and Malaysia, with returns equivalent of US $1.3 million and $2.15 million respectively. The latter success was associated with understanding of the social implications and situation at village level, well developed extension packages, government leadership, and training workshops for senior policy administrators, laboratory staff and livestock officers. (http://www.fao.org/docs/eims/upload/207692/7_1_1_cases.PDF). Tsetse fly eradication projects have had some success, especially where farmer-based and demand-driven approaches to control are adopted and where cohesive groups can function as the basis for collective action (Dransfield et al., 2001). Positive impacts of livestock research for poor producers have occurred through the introduction of new institutional forms, such as dairy cooperatives in India and with a supportive national policy and legislative environment. Nevertheless, many livestock projects have not had satisfactory long-term effects on the livelihoods of the poor (LID, 1999). In general, the uptake and impact of livestock technologies in developing countries is often constrained by the lack of a poverty reduction focus, their higher financial and labor demands, an overly narrow technical focus, inappropriate technologies, failure to take into account the social context of production, patterns of ownership and local knowledge and weak private sector development (Livestock in Development, 1999), or because wealthier farmers or herders captured the benefits (Heffernan et al., 2005).

**Social and economic impacts of GMOs depend on the socioeconomic and institutional circumstances of the country of introduction.**

| GOALS<br>L, E, S, D | CERTAINTY<br>C E | RANGE OF IMPACTS<br>-3 to +2 | SCALE<br>N | SPECIFICITY<br>Mainly in large scale farms in industrialized countries |
|---|---|---|---|---|

There have been positive farm level economic benefits from GMOs for large scale producers, but less evidence of positive impact for small producers in developing countries. The adoption of the commercially available GM commodity crops (over 90% of global area planted) has mostly occurred in large scale industrial, chemical intensive agricultural systems in North and South America (95.2% of production), with small areas in India and China (James, 2006), and the rest is shared among 16 other countries worldwide. There is little consensus among the findings from the assessments of economic and environmental impacts of GMOs. An analysis of the global impact of biotech crops from 1996 to 2006 showed substantial net economic benefits at the farm level; reduced pesticide spraying, decreased environmental impact associated with pesticide use and reduced release of greenhouse gas emission (Brookes and Barfoot, 2006). A different study of the economic impact of transgenic crops in developing countries found positive, but highly variable economic returns to adoption (Raney, 2006). In this case, institutional factors such as the national agriculture research capacity, environmental and food safety regulations, IPRs and agriculture input markets determined the level of benefits, as much as the technology itself (Raney, 2006). Adoption of GM cotton in South Africa is symptomatic not of farmer endorsement of GM technology, but of the profound lack of farmers' choice and a failure to generate sufficient income in agroecosystems without a high level of intensification (Witt et al., 2006). Other studies have concluded that GM technologies have contributed very little to increased food production, nutrition, or the income of farmers in less-developed countries (Herdt, 2006), or even led to deskilling of farmers (Stone, 2007). In Argentina, many large scale farmers have greatly benefited from the use of herbicide resistant soybeans (Trigo and Cap, 2003; Qaim and Traxler, 2004). However significant socioeconomic and environmental problems have arisen from the increased area of soybeans linked to the introduction of GM soybean for small-scale or landless farmers, which enabled them to produce at significantly lower costs, with expansion on marginal lands (Trigo and Cap, 2003; Benbrook, 2005; Joensen et al., 2005; Pengue, 2005). In India, claims regarding benefits or damages are highly controversial with reports presenting opposing data and conclusions (e.g. Qayum and Sakkhari, 2005 *vs*. Morse et al., 2005).

*3.2.3.2.2 Health and nutrition*

**Rates of hunger have been decreasing but hunger is still common despite the advances of AKST and the Green Revolution.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | -3 to +4 | G | Mostly in developing countries |

Although the Green Revolution and other AKST have had significant impacts on increased food supply, the reduction of hunger and malnutrition has been unevenly distributed across the world. Currently, the number of people defined as hungry in 2006 was 854 million people, of whom 820 million lived in Developing Countries (FAO, 2006e). In parallel, food consumption per person has risen from 2358 to 2803 kcal per day between the mid 1960's and late 1990's. Now, only 10% of the global population lives in countries with food consumption below 2200 kcal, while 61% live in countries consuming over 2700 kcal (FAO, 2005c). However the incidence of hunger has not declined in many countries of sub-Saharan Africa (FAO, 2005c), where population growth (3%) outstrips increases in food production (2%). In 2005, it was estimated that 13% of the world population (850 million people) are energy-undernourished, of whom 780 million were in developing countries (FAO, 2005c). Hunger is not explained by a simple relationship between food supply and population, as adverse agricultural conditions, poverty, political instability, alone or in combination, are contributing factors (Sen, 1981).

**Rates of malnutrition are decreasing, but undernutrition is still a leading cause of health loss worldwide despite AKST advances.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | -4 to +2 | G | Mostly in developing countries |

AKST has been important in reducing malnutrition, especially in mothers and children. Although the world food system provides protein and energy to over 85% people, only two-thirds have access to sufficient dietary micronutrients for good health (Black, 2003). Child stunting malnutrition reduced in developing countries from 47% in 1980 to 33% in 2000, but is still a major public health problem with 182 million stunted preschool children in developing countries (70% in Asia and 26% in Africa) (de Onis, 2000). Factors implicated include low national *per capita* food availability, lack of essential nutrients due to poor diet diversity, poor child breast feeding patterns, high rates of infectious disease, poor access to safe drinking water, poor maternal education, slow economic growth and political instability (de Onis, 2000). Under nutrition remains the single leading cause of health loss worldwide (Ezzati et al., 2003), and being underweight causes 9.5% of the total disease burden worldwide. In developing countries this is linked with nearly 50% of malaria, respiratory diseases and diarrhea. Selected dietary micronutrient deficiencies (iron, vitamin A and zinc deficiency) were responsible for 6.1% of world disease burden (Ezzati et al., 2003).

**A focus on increased production and food security rather than diet quality has contributed to a rise in obesity worldwide and the double burden of under and over-nutrition in developing countries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | -2 to+2 | G | Worldwide |

A focus on energy needs, rather than improved nutrition and access to a balanced and healthy diet, has been one factor in increasing overweight and obesity worldwide (Black, 2003; Hawkes, 2006). Increased food production and *per capita* availability together with a decline in world prices since the 1960s has created food energy abundance for more than 60% of the world(FAO, 2005c). Dietary and nutritional transitions have occurred worldwide, with actual patterns of diet change and hence health impacts varying (Popkin, 1998; Caballero, 2005). Socioeconomic, demographic and environmental changes have occurred that affect food availability, food choices, activity and life patterns (e.g. urbanization, work practices, transport, markets and trade) (Hawkes, 2006). Diet trends have resulted in widespread decreasing intake of fruits and vegetables and increasing intake of meat, sugar, salt and energy-dense processed foods (Popkin, 1998; WHO/FAO, 2003). Dietary fat now accounts for up to 26-30% of caloric intake, and there has been marked increases in both meat and fish intake (see 3.2.1). These dietary changes have contributed to rapidly rising obesity and its related chronic diseases such as ‘type 2’ diabetes, hypertension, heart disease and cancers globally (WHO/FAO, 2003). In 2005 more people were overweight (1.6 billion adults [age 15+]) than underweight worldwide and 400 million adults were obese (WHO, 2005a). This problem is now increasing in low- and middle-income countries (below 5% in China, Japan and certain African nations, to 40% in Colombia, Brazil, Peru (www.iaso.org), and over 75% in the Pacific), particularly in urban settings - almost 20% in some Chinese cities (WHO, 2003). In Africa, Latin America, Asia and the Pacific, there is now the double diet-related disease burden of under-nutrition and obesity (Filozof et al, 2001; Monteiro et al., 2002; Rivera et al., 2002; Caballero, 2005).

**Dietary diversity is a key element of a healthy diet.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | +2 to +4 | G | Worldwide |

With the increased focus on staple starch crops, and global food trends, dietary diversity has declined over recent decades (Hatloy et al., 2000; Marshall et al., 2001; Hoddinott and Yohannes, 2002). However, many studies have recognized the need for a diverse and balanced diet for optimum health (Randall et al., 1985; Krebs-Smith et al., 1987; Hatloy et al., 2000; Marshall et al., 2001). Healthy diets include fruits and vegetables, animal source proteins, and sources of fiber to (i) minimize the risks of cancer (Tuyns et al., 1987), vascular (Wahlquist et al., 1989) and cardiovascular diseases (Cox et al., 2000; Veer et al., 2000); (ii) optimize birth weight of children (Rao et al., 2001), maintain overall health (Ruel, 2002), and prolong life expectancy (Kant et al., 1993), and (iii) maximize earning capacity from manual labor (Ali and Farooq, 2004; Ali et al., 2006). Various measures and standards have been developed for food quality, which include Diet Quality Index (Patterson et al., 1994), Analysis of Core Foods (Kristal et al., 1990), and Healthy Eating Index (Kennedy et al., 1995). In addition, Dietary Diversity Scores are being devised to measure diet quality (Hatloy et al., 1998; Kant et al., 1993, 1995; Marshall et al., 2001; Ali and Farooq, 2004). A methodology has been developed to prioritize food commodities based on their total nutritive values (Ali and Tsou, 2000). Unlike food safety standards, measures of food quality or diet diversity have not been implemented nationally or internationally

**Food based approaches to tackle micronutrient deficiencies have long term benefits on health, educational ability and productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | +2 to +4 | R | Mainly in developing countries |

Although, the potential of food based dietary diversification to reduce micronutrient deficiency disease has not been fully explored or exploited (Ruel and Levin, 2000), new approaches to overcoming micronutrient deficiencies are focusing on diet diversification and food fortification. Food fortification has to date mostly been applied in industrialized countries, as technical, sociocultural, economic and other challenges have constrained their use in less developed countries (WHO, 2005c). Food fortification is potentially more cost effective and sustainable than treating people with food supplements and is compatible with giving greater attention to diversified production of fruits, vegetables, oilcrops and grain legumes, as well as diverse animal source proteins including fish, poultry and dairy products (FAO, 1997). It is likely that a combination of strategies, including greater emphasis on traditional foods (Leakey, 1999a), is required to tackle micronutrient malnutrition (Johns and Eyzaguirre, 2007).

**Animal source protein is one component of a healthy diet but rapid increases in livestock production and red meat consumption pose health risks by directly contributing to certain chronic diseases.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A/B | +3 to -3 | G | Worldwide |

Animal source protein can be an important component of a healthy diet, but moderate consumption of meat and fish is desirable. A rapid rise in meat consumption in high, middle and some low income countries is linked to increased rates of ischaemic heart disease (particularly related to saturated fat), obesity and colorectal cancer (Law, 2000; Delgado, 2003; Popkin and Du, 2003; Larsson and Wolk, 2006). In the lowest income countries, especially Africa, consumption of animal source foods is often low, leading to malnutrition (Bwibo and Neumann, 2003). Moderate fish consumption has health benefits, e.g., reducing rates of coronary heart disease deaths (Mozaffarian and Rimm, 2006). Replacing ruminant red meat by mono-gastric animals or vegetarian farmed fish would create sources of animal source protein which would reduce rates of chronic diseases. A positive environmental side-effect could be reduced methane gas emissions (McMichael et al., 2007).

**AKST has not solved food security problems for the rural poor.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -4 to -2 | R | Rural poor in developing countries |

The rural poor (who comprise 80% of those hungry worldwide) are dependent on environmental resources and services, are highly vulnerable to environmental degradation and climate change, and have poor access to markets, health care, infrastructure, fresh water, communications, and education. Wild and indigenous plants and animals are important to the dietary diversity and food security of an estimated 1 billion people (FAO, 2005b). Increased population pressures on forests and woodlands has led to a decline in gathered natural foods (Johns et al., 2006), which are often rich in nutrients, vitamins and minerals (Leakey, 1999a). The expansion of urban areas has also reduced the sources of fresh food from home gardens (Ali et al., 2006), as has the focus on large-scale, industrial production of crops and livestock at the expense of smaller mixed farming systems employed by the poor.

**AKST has led to improvements in food safety although microbiological and chemical hazards continue to cause a significant health problem.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, E, S | A | -3 to +4 | G | Worldwide |

The emphasis of current food safety is on reducing the transmission of food- and water-borne infectious disease related to production, processing, packaging and storage, and chemical and other non-infectious food contamination. The latter include environmental contaminants such as mercury in fish and mycotoxins, as well as food additives, agrochemicals and veterinary drugs, such as antibiotics and hormones (Brackett, 1999; Kitinoja and Gorny, 1999). To improve food safety and quality there has been increased attention to traceability, risk assessment, the provision of controls (Hazard Analysis Critical Control Point - HACCP) and the implementation of food safety standards, such as GAP, GMP like ISO 9000, EUREP GAP and HACCP. In addition, AKST has developed both simple and high-technology solutions to extend shelf life and make stored foods safer. Techniques include low-cost, simple technology treatment of wastewater for irrigation; cost-effective methods for reducing microbial load on intact and fresh-cut fruit and vegetables; improved efficacy of water purification, such as chlorination/ozonizations (Kader, 2003); refrigeration and deep freezing; food irradiation; modified atmosphere packaging, laboratory and production-line surveillance, and genetic engineering. However public concern about the potential risks associated with new technologies has led to calls for rigorous risk assessments based on international standards (WHO, 2002). These technologies, linked to better transport have increased year round access to healthy, safe food for many, but these public health benefits are unequally distributed and favor high-income consumers.

**Emerging human and animal infectious diseases are linked to poor or limited application of AKST.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | -2 to +2 | G | Worldwide |

Of 204 infectious diseases currently emerging in both high and low income countries, 75% are zoonotic (transmitted between animals and humans) (Taylor et al., 2001). They pose direct threats to human health and indirect socioeconomic impacts affecting rural livelihoods due to trade restrictions. Recent high-profile examples of these animal diseases infecting humans through the food chain include Bovine Spongiform Encephalopathy (BSE) in cows and avian influenza (H5N1) in poultry. In both cases transmission has been linked to low standards in the animal feed industry and the increase of anti-microbial resistance arising from the use of antibiotics in industrialized farming systems. As this resistance will limit prevention and treatment of these diseases, the World Health Organization recommended the elimination of subtherapeutic medical antibiotic use in livestock production in 1997, and called for strict regulation and phasing out of other subtherapeutic treatments, such as growth promotants (http://europa.eu/rapid/pressReleasesAction.do?reference=IP/03/1058&format=HTML&aged=0&language=EN&guiLanguage=en ). Adequate surveillance and control programs have not been introduced in many countries.

**The health focus of industrial food processing and marketing has mainly been on adding value and increasing shelf-life, and not on improving nutrition.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -2 to +2 | G | Worldwide |

AKST has focused on adding value to basic foodstuffs (e.g. using potatoes to produce a wide range of snack foods). This has led to the development of cheap, processed food products with long shelf life but reduced nutritive value (Shewfelt and Bruckner, 2000). Post-harvest treatments to extend shelf life of fruit and vegetables degrade provitamin A, such as β-carotene, and reduce the bioavailability of nutrients (AVRDC, 1987; Zong et al., 1998). The benefits of this food processing technology tend to be unequally distributed between producer and retailer, with increasingly lower percentages of the final cost of processed food reaching the rural producers. In developed countries this has led to concerns that retailers may abuse their market power *vis-à-vis* other producers and consumers. The emphasis on 'adding value' has also has also lowered the incentive to promote healthy fresh produce such as fruits and vegetables. Recent initiatives to develop processed 'health foods' are predominantly aimed at rich consumers (Hasler, 2000). Food labeling and health claims on packaged foods are a major source of nutritional information for consumers (EHN, 2001), but voluntary labeling approaches (such as guideline daily amounts) are difficult for consumers to understand, reducing their ability to make informed choice about the nutritional value of the foods. As mentioned earlier, processed energy-dense foods (high in fat, salt and sugar) are contributing to increasing rates of obesity and associated chronic diseases (Nestle, 2003).

**Agricultural production and trade policies have influenced negative trends in global nutrition and health.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, S, D | A | -3 to -1 | G | Worldwide |

Despite the clear links between diet, disease and health, agricultural policy has been dominated by production rather than diet objectives (Lang and Heasman, 2004). There is international agreement on the requirements of a healthy diet (WHO/FAO 2003), and the ability of diets rich in fruits and vegetables to reduce diseases like heart disease, stroke, and many cancers (Ness and Powles, 1997; WCRF/AICR, 1997; Bazzano et al., 2001; Lock et al., 2005). Saturated fatty acids (naturally present in animal fats) lead to increased serum cholesterol levels and a higher risk of coronary heart disease. Trans fatty acids, caused by industrial hydrogenation of vegetable or marine oils by the food industry, cause higher risks of heart disease (Willet et al., 2006; Mozaffarian et al., 2006). Agricultural policies and production methods influence what farmers grow, and what people consume, through their influence on food availability and price (Hawkes, 2007). The liberalization of agricultural markets and the rise of a global, industrialized food system, have had major effects on consumption patterns, resulting in high public health costs and externalities (Lang and Heasman, 2004). This has resulted in a convergence of consumption habits worldwide, with lower income groups increasingly exposed to energy dense foods, while high-income groups benefit from the global market (Hawkes, 2006).

**Agrochemical use can have both positive and negative impacts on health.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, L, S | A | -3 to 0 | R | Mainly in developing countries |

Agrochemicals have been responsible for increasing food production and as part of the control of some important human diseases such as malaria. However, they can also cause a wide range of acute and chronic health problems (O’Malley, 1997; Kishi, 2005). Chronic health effects include reproductive, neurological, developmental/learning disabilities, endocrine-disruption, and some cancers. WHO has estimated that there are at least 3 million cases each year of pesticide poisoning worldwide, one million of which are thought to be unintentional poisoning and two million suicide attempts, leading to about 220,000 deaths annually (WHO, 1986). The majority of these cases occur in developing countries where knowledge of health risks and safe use is limited, and harmful pesticides, whose use may be banned in developed regions, are easily accessible (Smit, 2002). In developing countries, acute poisoning of agricultural workers can result from poor training and lack of proper safety equipment (Repetto and Baliga, 1996), as well as an inability to read and understand health warnings. Small-scale farmers may be too poor to purchase the necessary protective equipment (if available), and may not have access to washing facilities in the fields or at home. Studies of farm workers and children living in agricultural areas in the USA and in developing countries indicate that adverse health impacts are also experienced by children playing around pesticide treated fields, and people drinking pesticide contaminated water supplies (Curl et al., 2002; Fenske et al., 2002), Pesticide related illness results in economic losses (Cole et al., 2000).

**Poor health has negative impacts on agricultural productivity and the application of AKST.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, | A | -4 to -2 | R | Mainly Developing countries |

Agricultural production can be negatively affected by the poor health of agricultural workers, resulting from malnutrition, chronic non-communicable diseases and infectious diseases (Croppenstedt and Muller, 2000; Jayne et al, 2004). Poor health also affects farmers' ability to innovate and develop farming systems (Jayne et al., 2004). Many studies show that communities with high disease prevalence experience financial and labor shortages. They respond by changing crops and reducing the area of land under cultivation, consequently decreasing productivity (Fox, 2004; Jayne et al., 2004). Ill health among families of producers can further reduce household income or other outputs of farm work as the able bodied absent themselves from work in order to care for their sick family members (Jayne et al., 2004). In developing countries these issues are most clearly illustrated by the impact of HIV/AIDS (Fox, 2004; Jayne et al., 2004), which, due to reductions in life expectancy, also results in loss of local agricultural knowledge and reduced capacity to apply AKST.

**Agriculture has one of the worst occupational health and safety records.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | -4 to 0 | R, G | Worldwide |

Irrespective of age, agriculture is one of the three most dangerous occupations (with mining and construction) in terms of deaths, accidents and occupational-related ill-health (ILO, 2000). Half of all fatal accidents worldwide occur in agriculture. Many agricultural practices are potentially hazardous to the health of agricultural workers, including use of agrochemicals and increasing mechanization. Agriculture is traditionally an under regulated sector in many countries and enforcement of safety regulations is often difficult due to dispersed nature of agricultural activity and lack of awareness of the nature and extent of the hazards. It is estimated that some 132 million children under 15 years of age work on farms and plantations worldwide due to lack of policies to prevent agricultural child labor (ILO, 2006). This work exposes them to a number of health hazards, as well as removing them from education. AKST has not addressed the tradeoffs of policies and technologies to minimize harm and maximize the health and livelihoods benefits.

**The limited availability of supplies of fresh potable water is a health issue, especially in dry areas with diminishing water resources and where there are threats from nitrate pollution of water bodies and aquifers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | -2 to 0 | R | Developing countries mainly |

The lack of access to clean drinking water is estimated to be responsible for nearly 90% of diarrheal disease in developing countries (Ezzati et al., 2003). Reducing this health hazard and improving the access to clean drinking water is one of the Millennium Development Goals;

currently Africa is not on track to meet these targets. In some areas of the Sahel, aquifers are becoming seriously polluted by N pulses reaching water tables (Edmunds et al., 1992; Edmunds and Gaye, 1997). This N is probably of natural origin, since N-fixing plants used dominate in natural vegetation and, in the absence of land clearance, the N was probably recycled in the upper soil profile through leaf litter deposition and decomposition. However, following deforestation, the nutrient recycling process is lost and N is slowly leached down the profile. High N contamination has serious implications for the future potability of groundwater for the human population and their livestock.

**The safety of GMO foods and feed is controversial due to limited available data, particularly for long-term nutritional consumption and chronic exposure.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E | C, E | -3 to 0 | N, R | Mainly in industrialised countries |

Food safety is a major issue in the GMO debate. Potential concerns include alteration in nutritional quality of foods, toxicity, antibiotic resistance, and allergenicity from consuming GM foods. The concepts and techniques used for evaluating food and feed safety have been outlined (WHO, 2005b), but the approval process of GM crops is considered inadequate (Spök et al., 2004). Under current practice, data are provided by the companies owning the genetic materials, making independent verification difficult or impossible. Recently, the data for regulatory approval of a new Bt-maize variety (Mon863) was challenged. Significant effects have been found on a number of measured parameters and a call has been made for more research to establish their safety (Seralini et al., 2007). For example, the systemic broad spectrum herbicide glyphosate is increasingly used on herbicide resistant soy bean, resulting in the presence of measurable concentrations of residues and metabolites of glyphosate in soy bean products (Arregui et al., 2004). In 1996, EPA re-established pesticide thresholds for glyphosate in various soybean products setting standards for the presence of such residues in herbicide resistant crop plants (EPA, 1996ab). However, no data on long-term consumption of low doses of glyphosate metabolites have been collected.

*3.2.3.2.3 Access to assets*

**Increased returns from agriculture result in improvements in the educational status of children.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S, D | B | 0 to +4 | G | Wide applicability |

The successful application of AKST results in improvements in the access of children to education. Enrolment in primary education has increased in developing countries (86% overall). This is highest in southern Asia (89%) but lower in some countries of Africa, western Asia and Oceania (UN, 2006a). Numbers of children out of school are much greater in poor rural areas (30%) than in urban areas (18%); 20% of girls and 17% of boys do not attend primary school. A key factor linking agriculture and education is that women are more likely to invest their assets in children's food and education when they have control of the assets and the benefits from increased productivity (Quisumbing and Maluccio, 1999) (see 3.2.3.4).

**Access and rights to natural assets (agricultural, grazing, forest land and water) and the conditions and security of that access, critically affect the livelihoods of many of the world's poorest households.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | A | -4 to +4 | G | Wide applicability |

Land tenure systems are dynamic and subject to change; e.g., in situations of population expansion, competition for land for new investment opportunities, urban expansion and road development (Platteau, 1996; Barbier, 1997; Toulmin and Quan, 2000; Chauveau et al., 2006). Differences in access to land resources relate to status and power with migrants, women and people of lower social status being the most vulnerable to expropriation (Blarel, 1994; Jayne et al., 2003). Disputes over land are common in much of Africa (Bruce and Migot-Adholla, 1994; Place, 1995; Deininger and Castagnini, 2006). Households with land are generally better placed to make productive use of their own resources (especially labor), as well as to access capital for investment (Deininger, 2003). Conversely, land concentration and increasing landlessness may give rise to conflicts and threaten social stability, unless alternative investments and opportunities are available (Gutierrez and Borras, 2004; Mushara and Huggins, 2004; Cotula et al., 2006). In many countries, particularly in sub-Saharan Africa, there are a number of coexisting systems of authority related to land. The main contrast is between customary and statutory law, although these categories mask multiple secondary rights. Security of land tenure is seen as a precondition for intensifying agricultural production and as a prerequisite for better natural resources management and sustainable development and therefore a factor for poverty alleviation (Mzumara, 2003; Maxwell and Wiebe, 1998). Secure tenure is also important to facilitate access to credit and input markets, however, conclusions drawn about the effects of land tenure systems on investment and productivity vary considerably. Policies and programs establishing individual rights in land through land titling have not produced clear evidence showing tenure has led to greater agricultural growth (Quan, 2000), or to improved efficiency (Place and Hazell, 1993). In contrast, without supportive policies, it is difficult for poor small-scale farmers, particularly women, to enter emerging land markets (Toulmin and Quan, 2000; Quan et al., 2005). Despite women's key role in agricultural production, in many countries women's rights over land are less than those of men (Place, 1995; Lastarria-Cornhiel, 1997; Meinzen-Dick et al., 1997; Jackson, 2003). Formal rights to land for women can have an impact on intra-household decision making, income pooling, and women's overall role in the household economy as well as empowering their participation in community decision making (World Bank, 2005b). Government land registration processes have sometimes further entrenched women's disadvantage over land by excluding their rights and interests (Lastarria-Cornhiel, 1997). In some countries, land policy strategies have explored alternatives that limit open access while avoiding the rigidity of individual private ownership and titles; for example management by user groups (Ostrom, 1994) and more open participatory and decentralized policies and institutions for land and land rights management. Regarding water resources, poor communities are often adversely affected by limited access to water for drinking, domestic use, agriculture and other productive purposes. Water access has been improved by institutional and policy innovations in water management and water rights (see 3.2.4.1).

**Large scale applications of modern AKST in the water sector have resulted in winners and losers among rural communities.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S, D | B | -3 to + 2 | G | Wide applicability |

Large scale irrigation schemes have had important impacts on livelihoods. However, while building the value of assets for some, the displacement of populations is one of the notable negative consequences of irrigation schemes, especially where large scale infrastructure has been built. Dams have fragmented and transformed the world's rivers, displacing 40-80 million people in different parts of the world (WCD, 2000). Criteria for land allocation do not necessarily guarantee a place in the irrigated schemes for those who have lost their land and resettlement can result in impoverishment (Cernea, 1999)

**Access to energy provides important livelihood benefits and improves opportunities to benefit from AKST.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, L, E, S, D | A | 0 to +4 | R, N L | Wide applicability |

Energy is an essential resource for economic development (DFID, 2002), but more than 1.5 billion people are without access to electricity. In developing countries, approximately 44% of rural and 15% of urban households do not have access to electricity, while in sub-Sahara Africa, these figures increase to 92% and 42% respectively (IEA, 2006c). There is a direct correlation between a country's *per capita* energy consumption (and access) and its industrial progress, economic growth and Human Development Index (UNDP, 2006a). Estimates of the financial benefits arising from access to electricity for rural households in the Philippines were between $81 and $150 per month, largely due to the improved returns on education and opportunity costs from time saved, lower cost of lighting, and improved productivity (UNDP/ESMAP, 2002a). Affordable and reliable rural energy is important in stimulating agricultural related enterprises (Fitzgerald et al., 1990). However, rapid electrification, without the necessary support structures to ensure effectiveness and sustainability, does not bring benefits. Decentralized approaches to electricity provision delivered by private sector, NGOs or community based organizations are presenting viable alternatives that can improve access for rural households.

**Improved utilization of biomass energy sources and alternative clean fuels for cooking can benefit livelihoods, especially for women and children.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, L, E, S, D | B | 0 to +4 | N,L | Mainly developing countries |

More than 2.5 billion people use biomass such as fuel wood, charcoal, crop waste and animal dung as their main source of energy for cooking. Biomass accounts for 90% of household energy consumption in many developing countries (IEA, 2006c). Smoke produced from the burning of biomass using simple cooking stoves without adequate ventilation, can lead to serious environmental health problems (Ezzati and Kammen, 2002; Smith, 2006), particularly for women and children (Dasgupta et al., 2004). Women and children are most often responsible for fuel collection, an activity with competes significantly with time for other activities, including agriculture (e.g. 37 hours per household per month in one study in rural India) (UNDP/ESMAP, 2002b). Simple interventions such as improved stoves can reduce biomass consumption by more than 50% and can reduce the effects of indoor smoke (Baris et al., 2006).

**The successful achievement of development goals is greatest when social and local organizational development is a key component of technology development and dissemination and when resource poor farmers are involved in problem-solving.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S,D | B | 0 to +3 | G | Widespread in developing countries |

The social and cultural components of natural resource use and agricultural decision making are fundamental influences on the outcomes from AKST. They operate both at the level of individual actors and decision makers, and at group or community level. Community based approaches have had important results in promoting social cohesion; enhancing governance by building consensus among multiple stakeholders for action around problem issues; and facilitating community groups to influence policy makers (Sanginga et al., 2007). Community based, collective resource management groups that build trust and social capital increasingly common (Scoones and Thompson, 1994; Agrawal and Gibson, 1999; Pretty, 2003). Since the early 1990's, about 0.4-0.5 million local resource management groups have been established. In the US, hundreds of grass-roots rural ecosystem place-based management groups have been described as a new environmental movement (Campbell, 1994), enhancing the governance of 'the commons' and investment confidence (Pretty, 2003). They have been effective in improving the management of watersheds, forests, irrigation, pests, wildlife conservation, fisheries, micro-finance and farmer's research. In conservation programs, however, there are sometimes negative impacts from social capital; the social exclusion of certain groups or categories or the manipulation of associations by individuals with self-interest (Olivier de Sardan, 1995; Pretty, 2003). When promoting community participation and decision making, it is important to set in place mechanisms to ensure the participation of the most vulnerable or socially excluded groups such as women, the poorest, or those living in remote areas, to ensure their voices are heard and their rights protected (see 3.2.3.3).

**Initiatives to enhance social sustainability are strengthened if accompanied by policies that ensure the poorest can participate.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | 0 to +4 | G | Widespread in the tropics |

Poor people in the community are empowered by programs that build or transfer assets and develop human capital (health care, literacy and employment - particularly in off-farm enterprises) (IDS, 2006; UNDP, 2006b). The alternative and more costly scenario is the mitigation of livelihood and natural resource failure in poor rural areas, through long-term welfare support and emergency relief (Dorward et al., 2004).

3.2.3.2.4 Vulnerability and risk

**Although AKST has had many positive impacts, it is now clear that in some circumstances it has also been a strong negative driver/factor for exclusion/marginalization processes.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | -3 to 0 | G | Wide applicability |

Although AKST has often had positive benefits on peoples' livelihoods, there have also been negative impacts. Exclusion and marginalization processes such as poverty, hunger or rural migration, have often occurred because of differences in people's capacity to make use of knowledge and technology and to access resources (Mazoyer and Roudart, 1997). These differences are usually the result of discriminatory or exclusionary practices due to gender, class, age or other social variables. The implementation of new technology has implications for social differentiation, sometimes excluding farmers and their families from production and marketing. Target-oriented programs have responded to this problem by building in awareness of access issues relating to AKST into project design; by monitoring poverty related indicators throughout implementation and through accompanying institutional arrangements.

**Impacts of AKST have been more widely evident where they respond to, or are consistent with, the priority that the poor place on managing risk and vulnerability.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | 0 to +3 | R, L | Widespread in developing countries |

Established cultural traditions define the values and influence practices of small-scale communities. These typically emphasize low-input and risk-averse strategies which are at variance with the maximized production orientation of modern ASTK. Small-scale producers make rational decisions to optimize overall benefits from limited resources (Ørskov and Viglizzo, 1994). Thus, risk management, reduction of dependence on agricultural inputs, avoidance of long-term depletion of productive potential and more careful control of environmental externalities are important to them (Conway, 1997). Local knowledge and innovation respond to these priorities; an important assessment criterion of AKST is the extent to which it has helped to reduce both short-term local risk and vulnerability to external factors (e.g. economic changes, climate variability etc). Farmers' own assessment of risk is fundamental in influencing patterns of change in farming practices. High levels of risk are likely to negatively affect adoption (Meinzen-Dick et al., 2004). Perceptions of risk and the priorities of men and women vary in relation to their asset base; especially land and labor.

**The risks and costs associated with agriculture and rural development have recently been addressed by innovative microfinance initiatives.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S, D | D | 0 to +3 | N,L | Developing countries and poor urban areas of developed countries |

Based on successful experiences in various developing countries, a model, termed agricultural microfinance, is emerging (CGAP, 2005). The model combines the most promising features of traditional microfinance, traditional agricultural finance, leasing, insurance, and contracts with processors, traders, and agribusinesses. The original features of the model include innovative savings mechanisms, highly diversified portfolio risk, and loan terms and conditions that are adjusted to accommodate cyclical cash flows and bulky investments. Perhaps two of the most innovative products contributing towards greater rural development are those related to savings and remittances (Nagarajan and Meyer, 2005). Deposits are made to mobile deposit collectors at the savers’ doorstep, so reducing the transaction costs of rural farmers and households. Electronic innovations, such as the use of simple mobile phones, ATMs and remittance services, may also help drive down the costs of handling many small transactions in dispersed rural areas, and bring positive benefits to rural communities reliant on migrant labor. Successful remittance services are designed with clients to provide appropriate products and choose strategic partners at both ends of the remittance flow. Despite recent innovations, reaching the remote and vulnerable rural poor still remains a major challenge.

*3.2.3.2.5 Livelihood strategies – diversification, specialization and migration.*

The ways in which rural people combine and use their assets to make a living varies considerably between regions, individuals, households and different social groups. Choice of livelihood strategies is affected by economic, social and cultural considerations (e.g. what is appropriate according to gender, age, status). The range of livelihood choices is generally more restricted for the “asset” poor.

**Opportunities for diversification of rural income help to reduce vulnerability of the poor.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S, D | B | 0 to +4 | G | Widespread applicability |

Where agriculture and natural resources are the basis of livelihoods, small-scale farmers often spread their risks by diversification, as for example in mixed cropping systems (Dixon et al., 2001). Diversification affects agricultural productivity in different ways, in some cases positively (Ellis and Mdoe, 2003). Diversification is a response to an environment which lacks the conditions needed to reap the benefits of agricultural specialization: enterprises with efficient market integration, input and credit supply systems, knowledge access, relatively stable commodity pricing structures and supportive policies (Townsend, 1999). However, diversification is at variance with the emphasis of much agricultural policy in developing countries, which promotes more specialization in the production of high value products for national, regional and export markets. The larger, but lower value, markets for staple food crops are perceived as less risky than higher value markets, and less dependent on technical support services and inputs. Diversification and risk reduction strategies for rural households can include non-farm income; however, this is more difficult for the extreme poor, including female-headed households (Block and Webb, 2001). While there have been advances in rural non-agricultural employment opportunities, women's share in this did not greatly increase between 1990 and 2004 (UN, 2006a). In the general context of rising youth unemployment, young rural women in particular, have difficulty in entering the labor market. Some have argued that the increasing proportion of rural income from non- agricultural sources in Africa is indicative of the failure of agriculture to sustain the livelihoods of the rural poor (Reardon, 1997; Bryceson, 1999; Ellis and Freeman, 2004). There is evidence that the larger the proportion of non-farm to farm income, the larger the overall income.

**Where farm size or productivity can no longer sustain the needs of the household**, **alternative strategies of migration or investment are likely.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S, D | B | -1 to +3 | G R | Particularly in rainfed areas in developing countries |

Factors which increase vulnerability constitute severe challenges to the sustainability of livelihoods, e.g. population pressure, land and water shortages, declining productivity due to climate change, collapse of soil fertility, unstable and declining market prices. In these circumstances, some family members, often the young men, migrate to urban centers within or outside their country, in search of employment. These decisions are affected by generational and gender relationships (Chant, 1992; Tacoli, 1998; Bryceson, 1999), and contribute to the 'feminization' of agriculture (Song, 1999; Abdelali-Martini et al., 2003), and the increasing dependence of poor rural households on remittances for their survival. Increasingly the migrants include young women, leaving the old and the very young on the farm. In some cases, this has negatively affected agricultural production, food security, and service provision. Labor constraints have encouraged investment in technologies and options which are less demanding in labor, e.g. the establishment of tree crops which are profitable with lower labor inputs (Schreckenberg et al., 2002; Kindt et al., 2004; Degrande et al., 2006). Off-farm remittances have in some cases also encouraged broader investments, e.g. in Andean rural communities, remittances are used for small-scale agriculture, living expenses, and construction and home improvements aimed at the agro-tourism industry (Tamagno, 2003). There is also some evidence for other aspects of more sustainable farming at very high population densities and dependence on migrant community members (see 3.2.2.1.6), combining intensification of production and erosion control (Tiffen et al., 1994; Leach and Mearns, 1996).

#### 3.2.3.3 Participation and local knowledge systems

There is a growing body of work that systematically seeks to assess the impacts of participatory and gender sensitive approaches in agricultural research and development, and the role of local knowledge – for example the Systemwide Program on Participatory Research and Gender Analysis Program of the CGIAR (Lilja et al, 2001; 2004).

*3.2.3.3.1 Participatory research approaches*

**Participatory approaches have developed in response to the lack of economically useful, socially appropriate and environmentally desirable applications from AKST generated by agricultural research and development organizations.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S, D | C | -3 to +2 | G | Wide applicability |

There is much evidence that the technological advances of the Green Revolution have sometimes led to environmental degradation and social injustice (Conway, 1997). This has stimulated interest in new participatory approaches, methods and techniques to meet sustainability criteria (Engel et al., 1988) and to contribute to a new development paradigm (Jamieson, 1987) targeting development goals (Garrity, 2004)(see Chap 2). It has required major advances in the analysis of the behavior of the complex social systems found in rural communities. The growing interest in participatory approaches from the 1980s onwards, was in part a response to the contrast in the successes of Green Revolution technology in some contexts and its lack of, or negative, impact in others, particularly those characterized by high diversity, inaccessibility and weak institutions and infrastructure (Haverkort et al., 1991; Okali et al., 1994; Scoones and Thompson, 1994; Röling and Wagemakers, 1998; Cerf et al., 2000;). Participatory approaches, in which development agencies and technical specialists participate, use existing local skills and knowledge as the starting point (Croxton, 1999). They are built around a process that enables farmers to control and direct research and development to meet their own needs and to ensure a sense of ownership in decisions and actions (Engel et al., 1988). The main advantages of participatory approaches have been their responsiveness to local ecological and socioeconomic conditions, needs and preferences; building on local institutions, knowledge and initiatives and fostering local organizational capacity. Criticisms have focused on their resource requirements, the difficulties of scaling-up successes from small focus areas (Cooke and Kothari, 2001), the lack of radical change in institutional relationships and knowledge sharing, and the limited engagement with market and policy actors.

**Participatory approaches to genetic improvement of crops and animals results in better identification of farmer's requirements and preferences, leading to higher levels of adoption and benefit.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, S | B | 0 to +3 | G, N, L | Wide applicability |

In cereals and legumes, participatory approaches have been promoted in response to perceived weaknesses in conventional variety testing and formal release procedures which have not delivered suitable varieties to farmers in marginal environments, especially, but not exclusively, small-scale farmers (Witcombe et al., 1998). Formal release systems are often centralized, use a research station or other atypically favorable environment for testing, and select for average performance. Farmers or consumers are also rarely involved in this process. Consequently, varieties from these conventional release systems are often poorly adapted to small-scale farmer conditions and environments. Similarly, they have not always met the farmers' requirements for multipurpose uses (e.g. fodder and seed), or have not had acceptable post-harvest characteristics (e.g. easy to thresh/process, good taste, good storability). Participatory crop development allows for the better identification of farmer preferences and the requirements of their systems of production as well as optimizing local adaptation through the capture of Genotype X Environment interactions. Genetic diversity can also benefit from participatory approaches as farmers usually select and introduce cultivars that are unrelated to the modern varieties already grown (Witcombe et al., 2001). Other benefits of the participatory approach include a shortened breeding cycle in which new varieties are grown by farmers prior to the 12-15 year period of formal multilocational testing and release. This considerably increases the cost-benefit ratios, net present value and net social benefit (Pandey and Rajatasereekul, 1999). Another benefit of participatory breeding is enhanced compatibility with local or informal seed systems, which is especially important in times of extreme climatic and other stresses. Participatory approaches in livestock research have responded to criticisms that technologies were developed but seldom delivered, or if delivered, did not benefit poor farmers/herders (Hefferman et al., 2005) and have demonstrated the importance of understanding the particular needs and circumstances of resource poor farmers, building on local knowledge. These approaches have been more appropriate to farmer circumstances and are more likely to be adopted (Catley et al, 2001; Conroy, 2005); however, the benefits for crop and livestock sectors are largely experienced at local or regional levels, and the problem of scaling-up remains.

**Participatory approaches have been successfully developed for the domestication of indigenous trees for integration into agroforestry systems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S,D | D, E | 0 to +2 | R | Especially relevant to the tropics |

Throughout the tropics local tree species provide traditional foods and medicines (Abbiw, 1990; Villachica, 1996; Leakey, 1999a; Walter and Sam, 1999; Elevitch, 2006) many of which are marketed locally (Shackleton et al., 2007). Some of these species are being domesticated using a participatory approach to cultivar production (Leakey et al., 2003; Tchoundjeu et al., 2006), using simple and appropriate vegetative propagation methods (Leakey et al., 1990) so that local communities are empowered to create their own opportunities to enter the cash economy (Leakey et al., 2005a) (see 3.2.1.2.1 and 3.2.2.1.6). The use of participatory approaches ensures that the benefits of domestication accrue to the farmers. In this respect, these techniques are in accordance with the Convention on Biological Diversity (Articles 8 and 15) and provide a politically and socially acceptable form of biodiscovery. It is clear that this approach is also encouraging the rapid adoption of both the techniques and the improved cultivars (Tchoundjeu et al., 2006).

**Participatory approaches are important in addressing knowledge-intensive, complex natural resource management problems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | D, E | 0 to +2 | G | Widespread applicability |

In an impact assessment of participatory approaches to development of cassava based cropping systems in Vietnam and Thailand (Dalton et al., 2005), participating farmers gained additional yield benefits, compared with those who merely adopted the new planting material. The integration of management practices into the participatory learning activities resulted in a better understanding of the interrelationships between system components and led to efficiency gains.

**Community entry and participatory approaches have higher initial costs, but improved efficiency in technology development, capacity strengthening and learning.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S, D | B, E | +2 | N, L | Subsistence households of the semi-arid tropics. |

Crop management research increasingly involves farmers in the participatory evaluation of new technologies, identifying adoption constraints and opportunities for improving farm performance to produce more sustainable impact. Between 1999 and 2001, ICRISAT and its partners in Malawi and Zimbabwe evaluated the impact of participatory research in connection with a range of 'best bet' soil fertility and water management technologies. The main findings were that community entry and participatory approaches that engage farmers in decision making throughout the research-development-diffusion-innovation process improved efficiency and impact, both through the development of relevant technology and in building farmers' capacity for experimentation and collective learning, but that these benefits had higher initial costs than traditional approaches (Rusike et al., 2006, 2007). The study recommended that public and NGO investments be targeted to build wider-scale district and village-level innovation clusters to make the projects more sustainable over a larger area. Similarly, in Colombia, participatory approaches with local agricultural research committees showed significant social and human capital benefits for members (http://www.prgaprogram.org/index.php?module=htmlpages&func=display&pid=12). However, in Honduras, where educational levels were lower and poverty higher, it was found that the process took longer; because of the need for more intensive assisted learning and social development to support the participatory technology component (Humphries et al., 2000).

*3.2.3.3.2 Indigenous knowledge and innovation systems*

**The complex and dynamic interactions between culture, society and nature and its resources are central to social and environmental sustainability.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | 0 to +4 | G | Worldwide |

Culture and tradition are important components of social sustainability. Traditional and local knowledge are part of culture and belief systems and codified in oral forms and in cultural and religious norms. These cultural meanings are embedded in local people's understanding of the environment, the management of natural resources and agricultural practice (Warren et al., 1995;

Posey, 1999). Yams are a staple crop of economic and cultural significance for the people in West Africa. For example, yams (*Dioscorea* spp.) play a vital role in society in the Dagomba ethnic group in north Ghana. About 75% of farmers in the northern region cultivate yam, as part of the African "yam zone" (Cameroon to Côte d'Ivoire) that produces 90%, or 33.7 million tonnes ,of the world's yams each year. During the celebration of the yam festival boiled yams are smeared on the surface of stones to secure the goodwill and patronage of deities. The Dagomba invoke their gods during the communal labor through which they exchange yam germplasm. Seed yam obtained through communal labor enjoys the blessing of the gods and produces high yields according to tradition. For the Dagomba, the yam has transcended agriculture to become part of the society's culture (Kranjac-Berisavljevic and Gandaa, 2004). Failure to recognize this would result in (a) the breakdown of traditional social structure; and (b) the loss of valuable yam germplasm in many cases.

**The knowledge of many indigenous communities has provided almost all their basic food, fibre, health and shelter needs as well as some products for cash income.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | A | +2 to +5 | G | Worldwide |

Typically, traditional and local KST has been developed through observation and experimentation, over many cycles, to achieve efficient and low-risk human welfare outcomes (Warren et al., 1995). A wide range of local institutions are significant in developing, disseminating and protecting this knowledge as it differs greatly from the specialized knowledge used by research and extension institutions working with agricultural science (Warren et al., 1989). The traditional actors harbor distrust for mainstream organizations and are comparatively marginalized by them. Consequently, identifying an appropriate and acceptable means of making use of traditional knowledge and protecting the valuable rights of indigenous communities to their traditional knowledge is a priority if this knowledge is not to be lost, and if the communities are to benefit (ten Kate and Laird, 1999). A good example is the patent protecting the rights of women in Botswana to traditional knowledge associated with Marula kernel oil. (www.phytotradeafrica.com/awards/criteria.htm).

**The important role of livestock for poor people's livelihoods has been sustained primarily through the effectiveness of indigenous knowledge.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, H, E, S, D | C | 0 to + 4 | L, N | Especially in the tropics |

Livestock are an important asset of many poor people, particularly in sub-Saharan Africa and south Asia (Thornton et al., 2002, 2004), providing a source of food, cash income, manure and draft power and strengthening their capacity to cope with income shocks (Ashley et al., 1999; Heffernan and Misturelli, 2001). In India, for example, livestock holdings are more equitably distributed than land holdings (Taneja and Birthal, 2003). Livestock ownership directly and indirectly affects the nutritional status of children in developing countries (Tangka et al., 2000). In Africa, the livestock sector, particularly in arid and semiarid areas, depends to a large extent on traditional and local knowledge for animal management and animal breeding (Ayantude et al., 2007, but receives little investment in international and national research. The depth of local knowledge has advantages when developing localized initiatives, for example, in animal feeding and forage production. Productivity in animal agriculture systems can be increased under dry conditions without great external inputs (Lhoste, 2005). Participatory methods for diagnosis of animal diseases have also shown promise, both in characterization of diseases and the linkages between local knowledge and modern veterinary knowledge (Catley et al., 2001). Such participatory local analysis has been used to develop control programs adapted to local conditions and knowledge (Catley et al., 2002).

*3.2.3.3.3 Linking scientific and indigenous knowledge and management capability*

**Significant gains have been made when farmer innovation (particularly in small-scale agriculture) is appropriately linked to formal AKST.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | 0 to +4 | G | Especially in the tropics |

Formal research and extension organizations have often not recognized the contribution of farmers' knowledge and strategies (Sibelet, 1995; Richards, 1985). However, there are good examples in plant breeding where farmers have communicated their local knowledge to researchers, and worked together in experimentation and decision making (Hocdé, 1997), researchers and stakeholders jointly designing experimentation, sharing and validating results (Liu, 1997; Gonzalves et al., 2005; Liu and Crezé, 2006). Agroforestry researchers working with farmers have investigated progressively more complex issues together, integrating biophysical and socioeconomic disciplines to resolve the sustainability problems in areas where poverty and environmental degradation coexist. This has required a unique mixture of new science (Sanchez, 1995) with local understanding of the day-to-day concerns of resource-poor farmers; the approach enhances the adoption of new ideas and technologies (Franzel and Scherr, 2002). Innovations like these evolve as a result of collective learning as well as from the pressure to constantly adapt to the changing economic environment.

**The influence of social institutions on land management, based on local knowledge and norms, may be undermined by policies based on the different perspectives of professionals.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | C | -3 to 0 | L | Widespread applicability |

Local knowledge, and the local institutions associated with it, have been regarded as an important foundation for community-based natural resource management and biodiversity conservation. However, this has been challenged as a romantic view, dependent on conditions of low population density, lack of modern technology and limited consumer demand (Attwell and Cotterill, 2000). The over-exploitation of natural capital has been widely attributed to a number of factors, including the loss of social institutions at the community level. In some cases this arises from changes in local systems of administration and governance. In India, the breakdown of regulations on livestock resulted in unregulated grazing (Pretty and Ward, 2001), while water resource degradation followed the replacement of collective irrigation systems by private ownership. Similarly, the failure of many formal attempts to halt rotational shifting cultivation in Thailand, Laos and Vietnam was, at its most fundamental level, associated with differing perspectives. That is, 'policy makers believed that shifting cultivation was the main cause of environmental problems such as floods and landslips' (Bass and Morrison, 1994). whereas others recognized the dynamic and diverse types of shifting cultivation in which farmers engaged, and the associated economic, social, cultural and environmental values.

**Institutions are crucial for sustainable development; the innovation systems approach offers more insights than previous paradigms into the complex relationships of technology development and diffusion.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | 0 to +3 | G | Widespread applicability |

The linear model of research and extension in which innovations are transferred as products from researchers to farmers via intermediaries in extension, has been challenged by experience showing that the pathways for technical changes are more diverse. In the last 15 years, the importance of knowledge in innovation processes has been more clearly recognized (Engel and Röling, 1989; Röling, 1992;). Knowledge is considered as a factor of production; considered by some to be more important than land, capital and labor. More recent approaches view innovation as a complex social process (Luecke and Katz, 2003) which takes multiple forms and involves the participation and interaction of a diversity of key actors and organizations (Sibelet, 1995; Spielman, 2005). These relationships or networks, 'the innovation system', operate within specific institutional and cultural contexts. Similarly, evaluation approaches have shifted from focusing on impacts of research to tracking the institutional changes and effective operation of the innovation systems (Hall et al., 2003). The innovation systems approach emphasizes continuous learning and knowledge flows, interaction of multiple actors and institutional change. Innovation Systems thinking has encouraged greater awareness of the complexity of these relationships, the processes of institutional learning and change, market and non-market institutions, public policy, poverty reduction, and socioeconomic development (Hall et al., 2003; Ferris et al., 2006). However, the approach does not explicitly engage with poverty and development agendas by examining the relationship between innovation systems, economic growth and the distributional effects on poverty reduction and policy options which would support this (Spielman, 2005).

**Devolution of resource management to local institutions has been successful where targeted support and enabling conditions were in place.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S, D | B | 0 to +3 | G | Widespread applicability |

Local institutions have the capacity to manage local resources and avert possible "tragedies of the commons" (Ostrom, 1992). Rules can be created to accommodate the heterogeneity found within communities (Agrawal and Gibson, 1999; Ostrom, 2005) and there are opportunities for co-management with government (Balland and Platteau, 1996). In conservation programs, the participation of the range of stakeholders in consensus building and consideration of benefit distribution reduces the risk of conflict and the costs of implementation and control, and increases the chances of sustainability (Borrini-Feyerabend, 1997; Guerin, 2007). In some cases, (e.g. the transfer of irrigation management to communities) the drive to establish local management has led to rigid, hierarchical user associations with functional and democratic short-comings (Agrawal and Gupta, 2005). However, research in the irrigation sector has identified that a supportive legal policy framework, secure water rights, local management capacity development and favorable cost/benefit relationships, are conditions favoring the successful transfer of management to communities (Shah et al., 2002). These characteristics encourage farmers' contributions and create a strong sense of ownership, which together lead to better subsequent operations and maintenance (Bruns and Ambler, 1992). Finally, research has shown the diversity and complexity of water rights in many developing countries and the importance of recognizing both formal legal rights and customary or indigenous rights in a 'pluralistic' approach (Bruns, 2007).

**Local or informal seed systems provide most seed used by farmers and are increasingly being used to deliver new varieties to farmers.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| 1 | A | +1 to +5 | R | Developing countries |

Nearly all developing country farmers depend on their own seed, or seed obtained locally from relatives or markets, for planting (Almekinders and Louwaars, 1999; Tripp, 2001). In contrast, most new varieties released in developing countries originate from public sector organizations, Hybrid maize is the exception; it originates from the private sector and seeds are delivered through commercial networks (Morris, 2002), although these are not tailored to specific local situations. Local seed systems are therefore very important. Typically they support the local economy and are very robust and effective. Studies in India have shown that seed can move many kilometers through these informal systems, and that local entrepreneurs quickly act to meet a demand for seed (Witcombe et al., 1999). Consequently, a number of initiatives have built on informal seed systems to distribute seed. For example, relief agencies promote these systems by using seed vouchers in times of drought or civil unrest (Sperling et al., 2004). The Program for Africa's Seed Systems (funded by the Bill and Melinda Gates Foundation) is promoting the distribution of improved crops varieties through private and public channels, including community seed systems.

**Scaling up the adoption of new technologies requires new approaches to partnerships and information sharing.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | C | -2 to +2 | G | Widespread applicability |

Adoption and impact of new agricultural technologies have been negatively affected by overlooking the human/cultural issues, ignoring local knowledge systems, and reducing the solution of agricultural problems to merely technology (Feder et al., 1985). The factors affecting adoption of technological innovations are numerous and complex. The interaction of technologies with the economic, social, cultural and institutional context influences the scale of adoption (Feder et al., 1985). Factors shown to affect adoption include complementarity with existing systems and practices, the relative 'profitability' and benefits of alternative technologies; and the incentives of the policy environment. Partnership networks and information sharing are needed for scaling up (Lilja et al, 2004); this is particularly important in non-seed based knowledge intensive technologies.

3.2.3.4 Learning and capacity strengthening

A key factor for widescale adoption of new AKST is the dissemination of information to the farmers by extension, farmer training and information management. Recent advances in ICT provide important new tools.

*3.2.3.4.1 Extension and training*

**Education and training contribute to national economic wellbeing and growth.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S, D | B | 0 to +4 | G | Widespread applicability |

Countries with higher levels of income generally have higher levels of education. Human capital, which includes both formal education and informal on-the-job training, is a major factor in explaining differences in productivity and income between countries (Hicks, 1987). Agricultural education plays a critical role in the transfer of technology and agricultural extension makes an important economic contribution to rural development (Evenson, 1997). Agricultural centers of excellence are yielding new technologies, and agricultural education is assisting with technology transfer activities by being part of interdisciplinary research programs. Informal mechanisms for information sharing, such as farmer-to-farmer models of agricultural development, is increasing in importance (Eveleens et al., 1996).

**A better understanding of the complex dynamic interactions between society and nature is strengthening capacity for sustainable development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, E, S | B | 0 to +3 | G | Widespread applicability |

Formal capacity development in developing countries goes beyond disciplinary expertise. It produces broad-based professionals that recognize the 'systems' nature of innovation and change, and its relationships with society (Pretty, 2002; FAO, 2005c). This is needed because of the inter-linking of sociological, cultural, agricultural and environmental issues and the differing and often conflicting land use needs and strategies of a multiplicity of stakeholders. Innovative methods and tools can effectively improve coordination, mediation and negotiation processes aimed at more decentralized and better integrated natural resources management (D'Aquino et al., 2003). The combined use of modeling and role-playing games helps professionals and stakeholders to understand the dynamics of these interactions (Antona et al., 2003).

**Lack of appropriate education/extension and learning opportunities are a constraint to technology transfer, trade and marketing, and business development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | A | -5 to 0 | G | Worldwide |

Many developing countries have large numbers of illiterate people. This is a constraint to economic and social development, as well as agriculture (Ludwig, 1999). Some important goals include the rehabilitation of university infrastructures, particularly information and communication facilities; organizational designs that link institutions of higher education to hospitals, communities, research stations, and the private sector; and curricula and pedagogy that encourage creativity, enquiry, entrepreneurship and experiential learning (Juma, 2006).

**Gender imbalances in agricultural extension, education and research systems limit women's access to information, trainers and skills.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | A | -2 to +4 | G | Worldwide |

There is a severe gender imbalance in agricultural extension services (Swanson et al., 1990; FAO, 1995; FAO, 2004a). Women constitute only 12.3% of extension workers in Africa (UN, 1995). Sensitivity to gender issues and vulnerable populations (disabled, HIV/AIDS affected, youth etc.) can determine the success or failure of training/extension activities. The number of women seeking higher education in agriculture is increasing in some developing countries, although female enrolment rates remain considerably lower than males (FAO, 1995). More women are now employed in national agricultural institutions than in the 1980s, but men still comprise the overwhelming majority of those employed, especially occupying in managerial and decision making positions (FAO, 1995).

**In Africa, expenditures related to agriculture and extension have been reduced in quantity and quality, thereby affecting productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S, D | B | -3 to 0 | R | Africa |

There has been a decline in government funding to agricultural extension services in many developing countries (Alex et al., 2002; Rusike and Dimes, 2004;). In the past, extension services financed by public sector (Axinn and Thorat, 1972; Lees, 1990; Swanson et al., 1997) were a key component of the Green Revolution. Today, two out of three farmers in Africa, particularly small-scale farmers and women farmers (FAO, 1990), have no contact with extension services, and worldwide publicly funded extension services are in decline. Critics of public extension claim that its services need to be reoriented, redirected and revitalized (Rivera and Cary, 1997) as the poor efficiency of traditional extension systems has undermined interest in them (Anderson et al., 2004).

**Both public and private delivery services can provide agricultural extension for modern farming.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | 0 to +5 | G | Worldwide |

There is a trend towards the privatization of extension organizations, often as parastatal or quasi-governmental agencies, with farmers asked to pay for services previously received free (FAO, 1995; FAO, 2000a; Rivera et al., 2000). This trend is stronger in the North than the South (Jones, 1990; FAO, 1995). Inclusion of the private sector can ensure competition and increase the efficiency of agricultural service delivery, especially with regard to agricultural input-supply firms (Davidson et al., 2001). However, problems exist in terms of incentives and stakeholder roles. In Southern Africa, private sector led development showed that private firms have significant potential to improve small-scale crop management practices and productivity by supplying farmers with new cultivars, nutrients, farm equipment, information, capital, and other services. However, market, institutional, government, and policy failures currently limit expanded private sector participation (Rusike and Dimes, 2004).

**The participation of a broad range of information providers on agricultural technologies, policies and markets, has been shown to play an important role in sustainable agricultural development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S, D | B | 0 to +3 | G | Wide applicability |

Currently, countries in Africa are searching for participatory, pluralistic, decentralized approaches to service provision for small-scale farmers. The private sector, civil society organizations and national and international NGOs are increasingly active in agricultural research and development (Rivera and Alex, 2004), supporting local systems that enhance the capacity to innovate and apply knowledge. In the poorest regions, NGOs have strengthened their extension activities with poor farmers by using participatory approaches and developing initiatives to empower farmer organizations (Faure and Kleene, 2004).

**Community based participatory learning processes and Farmer Field Schools have been effective in enhancing skills and bringing about changes in practice.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | 0 to +3 | G | Wide applicability |

Agricultural extension and learning practitioners are increasingly interested in informal and community based participatory learning for change (Kilpatrick et al., 1999; Gautam, 2000; Feder et al., 2003). Group learning and interaction play an important role in changing farmer attitudes and increases the probability of a change in practice (AGRITEX, 1998) by recognizing that farming is a social activity, which does not take place in a social or cultural vacuum (Dunn, 2000). In Kamuli district in Uganda, a program to strengthen farmers' capacity to learn from each other, using participatory methods and a livelihoods approach, found that farmer group households increased their production and variety of foods, reduced food insecurity and the number of food insecure months and improved nutritional status (Mazur et al., 2006; Sseguya and Masinde, 2006).

Farmer Field Schools have been an important methodological advance to facilitate learning and technology dissemination (Braun et al., 2000; Thiele et al., 2001; van den Berg, 2003). Developed in response to overuse of insecticides in Asia rice farming systems, they have become widely promoted elsewhere (Asiabaka, 2002). In the FFS, groups of farmers explore a specific locally relevant topic through practical field-based learning and experimentation over a cropping season. Assessments of the impacts of farmer field schools have generally been positive, depending on the assumptions driving the assessment. FFS have significantly reduced pesticide use in rice in Indonesia, Vietnam, Bangladesh, Thailand, and Sri Lanka (where FFS farmers used 81% fewer insecticide applications), and in cotton in Asia (a 31% increase in income the year after training, from better yields and lower pesticide expenditure) (Van den Berg et al., 2002; Tripp et al., 2005). Opinions on positive impacts are not unanimous (Feder et al., 2004). Farmer Field Schools have been criticized for their limited coverage and difficulty in scaling up; the lack of wider sharing of learning, their cost in relation to impact (Feder et al., 2004), the lack of financial sustainability (Quizon et al., 2001; Okoth et al., 2003), the demands on farmers' time and the failure to develop enduring farmer organizations (Thirtle et al., 2003; Tripp et al., 2005; Van Mele et al., 2005).However, there are few alternative models for advancing farmers' understanding and ability to apply complex knowledge intensive technologies. There is potential for FFS to self-finance in some cases (Okoth et al., 2003). FFS can stimulate further group formation (Simpson, 2001), but sharing local knowledge and sustaining relationships with different stakeholder groups post-FFS has often not been given sufficient attention (Braun et al., 2000).

**International organizations are training community workers and promoting important participatory approaches to rural development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, | B | 0 to +2 | G | Widespread in developing countries |

The World Agroforestry Centre is an example of one international institution which is providing training to farmers, through mentorship programs with Farmer Training Schools, scholarships for women's education, support of young professionals in partner countries and the development of Networks for Agroforestry Education, e.g. ANAFE (124 institutions in 34 African countries) and SEANAFE (70 institutions in 5 South East Asian countries) (Temu et al., 2001). Similarly, agencies such as the International Foundation for Science (www.ifs.se), and the Australian Centre for International Agricultural Research (www.aciar.gov.au), provide funds to allow graduates trained overseas to re-establish at home. At IITA in West Africa, the Sustainable Tree Crops Program is training groups of Master Trainers, who then train 'Trainers of Trainers', and eventually groups of farmers in the skills needed to grow cocoa sustainably (STCP Newsletter, 2003). The results of this initiative are promising (Bartlett, 2004; Berg, 2004), but there still remain crucial problems related to (i) the need for strong farmers' governance to monitor and assess extension activities, (ii) sustainable funding with fair cost sharing between the stakeholders including the State, private sector, farmer organizations, and farmers, and (iii) the need for Farmer Field Training to evolve into community-based organizations, to enable the community to continue benefiting on a sustained basis from the momentum created (Mancini, 2006).

**Environmental and sustainable development issues are being included in extension programs.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S | B | -2 to +4 | G | Wide applicability |

Extension services are now including a larger number of stakeholders that are not farmers in their target groups. Increasingly environmental and sustainable development issues are being incorporated into agricultural education and extension programs (van Crowder, 1996; Garforth and Lawrence, 1997; FAO, 1995).

*3.2.3.3.2 Information management*

ICTs are increasingly being used to disseminate agricultural information, but new techniques require new forms of support.

**Proper information management is frequently a key limiting factor to agricultural development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -4 to +4 | G | Worldwide |

Information access is limited in low-income countries, but farmers have an array of informal and formal sources (extension leaflets, television, mobile films, etc) from which they obtain information (Olowu and Igodan, 1989; Nwachukwu and Akinbode, 1989; Ogunwale and Laogun, 1997). In addition, village leaders, NGO agents and farmer resource centers are used as information hubs so that information and knowledge about new technologies and markets diffuse through social networks of friends, relatives and acquaintances (Collier, 1998; Conley and Udry, 2001; Fafchamps and Minten, 2001; Barr, 2002; ). Inevitably, issues of equitable access and dissemination arise as marginalized populations tend to be bypassed (Salokhe et al., , 2002). The challenge is how to improve accessibility of science and technology information to contribute to agricultural development and food security. This challenge is multidimensional, covering language issues as well as those of intellectual property and physical accessibility (World Bank, 2002; Harris, 2004).

**ICTs are propelling change in agricultural knowledge and information systems, allowing the dissemination of information on new technologies, and providing the means to improve collaboration among partners.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | 0 to +4 | G | Worldwide |

Information and Computer Technologies (ICT) are revolutionizing agricultural information dissemination (Richardson, 2006). Since the advent of the internet in the 1990s, communications technologies now deliver a richer array of information of value to farmers and rural households (Leeuwis, 1993; Zijp, 1994; FAO, 2000c); extension services deliver information services interactively between farmers and information providers (FAO, 2000c) via rural telecenters, cellular phones, and computer software packages. Important ICT issues in rural extension systems include private service delivery, cost recovery, and the "wholesaling" of information provided to intermediaries (NGOs, private sector, press, and others) (Ameur, 1994). In rural areas, ICTs are now used to provide relevant technical information, market prices, and weather reports. The Livestock Guru™ software program was created as a multimedia learning tool which enables farmers to obtain information on animal health and production and has had greater impact than more conventional media, illustrating the potential of these tools to help meet global agricultural and poverty alleviation objectives (Heffernan et al., 2005; Nielsen and Heffernan, 2006). ICTs help farmers to improve labor productivity, increase yields, and realize a better price for their produce (www.digitaldividend.org/pubs/pubs_01_overview.htm). A market information service in Uganda has successfully used a mix of conventional media, Internet, and mobile phones to enable farmers, traders, and consumers to obtain accurate market information resulting in farmer control of farm gate prices. (http://www.comminit.com/strategicthinking/st2004/thinking-579.html). Similar services exist in India, Burkino Faso, Jamaica, Philippines and Bangladesh (www.digitaldividend.org/pubs/pubs_01_overview.htm). ICT also provides the opportunity to create decision support systems such as e-consultation or advisory systems to help farmers make better decisions. ICT facilitates smooth implementation of both administrative and development undertakings. However with these ICT advances comes the task of managing and disseminating information in an increasingly complex digital environment.

**Advances in information technology are providing more tools for agricultural information management.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -2 to +3 | G | Wide applicability |

Due to advances in ICT, international organizations such as FAO have been able to respond to the need for improved information management by providing technical assistance in the form of information management tools and applications, normally in association with advice and training (http://www.fao.org/waicent). Agricultural thesauri like AGROVOC are playing a substantial role in helping information managers and information users in document indexing and information retrieval tasks.

**ICTs have widened the “digital divide” between industrialized and developing countries, as well as between rural and urban communities.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -2 to +3 | G | Wide applicability |

Although ICT improve information flow, not all people have equal access to digital information and knowledge of the technology creating a ‘digital divide’, a gap between the technology-empowered and the technology-excluded communities (http://www.itu.int/wsis/basic/faqs.asp; Torero and von Braun, 2006). Digital information is concentrated in regions where information infrastructure is most developed, to the detriment of areas without these technologies (http://www.unrisd.org). This, together with the ability of people to use the technology, has had an impact on the spread of digital information (Herselman and Britton, 2002). The main positive impacts on poverty from ICTs have been from radio and from telephone access and use, with less clear impacts evident for the internet (Kenny, 2002).

3.2.3.4 Gender

Farming practices are done by both men and women, but the role of women has typically been overlooked in the past. Resolving this inequity has been a major concern in recent years. For social and economic sustainability, it is important that technologies are appropriate to different resource levels, including those of women and do not encourage others to dispossess women of land or commandeer their labor or control their income (FAO, 1995; Buhlmann and Jager, 2001; Watkins, 2004).

**Women play a substantial role in food production worldwide.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -3 to +3 | G | Worldwide |

In Asia and Africa women produce over 60% and 70% of the food respectively, but because of inadequate methodological tools, their work is underestimated and does not normally appear as part of the Gross National Product (GNP) (Kaul and Ali, 1992; Grellier, 1995; FAO, 2002b; CED, 2003; Quisumbing et al., 2005; Diarra and Monimart, 2006). Similarly, women are not well integrated in agricultural education, training or extension services, making them 'invisible' partners in development. Consequently, women's contribution to agriculture is poorly understood and their specific needs are frequently ignored in development planning. This extends to matters as basic as the design of farm tools. The key importance of the empowerment of women to raising levels of nutrition, improving the production and distribution of food and agricultural products and enhancing the living conditions of rural populations has been acknowledged by the UN (FAO, www.fao.org/gender).

**Mainstreaming gender analysis in project design, implementation, monitoring and policy interventions is an essential part of implementing an integrated approach in agricultural development.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | 0 to +3 | G | Wide applicability |

The substantial roles of resource poor farmers such as women and other marginalized groups are often undervalued in agricultural analyses and policies. Agricultural programs designed to increase women's income and household nutrition have more impact if they take account of the cultural context and spatial restrictions on women's work as well as patterns of intra-household food distribution. The latter often favors males and can give rise to micronutrient deficiencies in women and children. The deficiencies impair cognitive development of young children, retard physical growth, increase child mortality and contribute to the problem of maternal death during childbirth (Tabassum Naved, 2000). Income-generating programs targeting women as individuals must also provide alternative sources of social support in order to achieve their objectives. In Bangladesh, an agricultural program aimed at improving women's household income generated more benefits from a group approach for fish production than from an individual approach to homestead vegetable production. The group approach enabled women members to overcome the gender restrictions on workspace, to increase their income and control over their income and to improve their status. In many countries of Asia, Africa, and Latin America, privatization of land has accelerated the loss of women's land rights. Titles are reallocated to men as the assumed heads of households even when women are the acknowledged household heads. Women's knowledge, which is critical to S&T and food security, becomes irreparably disrupted or irrelevant as a result of the erosion or denial of their rights (Muntemba, 1988; FAO, 2005d).

**The feminization of agriculture places a burden on women who have few rights and assets.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | -3 to 0 | G | Especially in the tropics |

Progress on the advancement of the status of rural women has not been sufficiently systematic to reverse the processes leading to the feminization of poverty and agriculture, to food insecurity and to reducing the burden women shoulder from environmental degradation (FAO, 1995). The rapid feminization of agriculture in many areas has highlighted the issue of land rights for women. Women's limited access to resources and their insufficient purchasing power are products of a series of inter-related social, economic and cultural factors that force them into a subordinate role to the detriment of their own development and that of society as a whole (FAO, 1996). The contribution of women to food security is growing as men migrate to the city, or neighboring rural areas, in search of paid jobs leaving the women to do the farming and to provide food for the family (FAO, 1998b; Song, 1999).

**At the institutional and national levels, policies that discriminate against women and marginalized people affect them in terms of access to and control over land, technology, credit, markets, and agricultural productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | -2 to +3 | G | Common occurrence |

Women's contribution to food security is not well reflected in ownership and access to services (Bullock, 1993; FAO, 2005c: FAO, 2006c). Fewer than 10% of women farmers in India, Nepal and Thailand own land; while women farmers in five African countries received less than 10% of the credit provided to their male counterparts. The poor availability of credit for women limits their ability to purchase seeds, fertilizers and other inputs needed to adopt new farming techniques. Although this is slowly being redressed by special programs and funds created to address women's particular needs, women's access to land continues to pose problems in most countries. In Africa, women tend to be unpaid laborers on their husbands' land and to cultivate separate plots in their own right at the same time. However, while women may work their own plots, they may not necessarily have ownership and thus their rights may not survive the death of their spouse (Bullock, 1993). In the case of male migration and *de facto* women heads of households, conflicts may arise as prevailing land rights rarely endow women with stable property or user rights (IFAD, 2004) .Traditionally, irrigation agencies have tended to exclude women and other marginalized groups from access to water— for example, by requiring land titles to obtain access to irrigation water (Van Koppen, 2002). Explicitly targeting women farmers in water development schemes and giving them a voice in water management is essential for the success of poverty alleviation programs. There are insufficient labor-saving technologies to enable women's work to be more effective in crop and livestock production. Armed conflict, migration of men in search of paid employment and rising mortality rates attributed to HIV/AIDS, have led to a rise in the number of female-headed households and an additional burden on women. Women remain severely disadvantaged in terms of their access to commercial activities (Dixon et al., 2001). In the short-term, making more material resources available to women, such as land, credit and technology at the micro level is mostly a question of putting existing policies into practice. Changes at the macro-level, however, will depend on a more favorable gender balance at all levels of the power structure. In Africa, the creation of national women's institutions has been a critically important step in ensuring that women's needs and constraints are put on the national policy agenda (FAO, 1990). The introduction of conventions, agreements, new legislation, policies and programs has helped to increase women's access to, and control over, productive resources. However, rural people are frequently unaware of women's legal rights and have little legal recourse if rights are violated (FAO, 1995). Given women's role in food production and provision, any set of strategies for sustainable food security must address women's limited access to productive resources. Ensuring equity in women's rights to land, property, capital assets, wages and livelihood opportunities would undoubtedly impact positively on the issue.

**Historically, women and other marginalized groups have had less access to formal information and communication systems associated with agricultural research and extension.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, S | B | -3 to 0 | G | Wide applicability |

Worldwide, there are relatively few professional women in agriculture (Das, 1995; FAO, 2004a). In Africa, men continue to dominate the agricultural disciplines in secondary schools, constitute the majority of the extension department personnel, and are the primary recipients of extension services. Men's enrolment in agricultural disciplines at the university level is higher than women's and is also increasing (FAO, 1990). Only 15% of the world's agricultural extension agents are women (FAO, 2004a). Only one-tenth of the scientists working in the CGIAR system are women (Rathgeber, 2002) and women rarely select agricultural courses in universities.

### *3.2.4 Relationships between AKST, coordination and regulatory processes among multiple stakeholders*

The interactions between AKST and coordination processes among stakeholders are critically important for sustainability. Technical changes in the form of inventions, strengthened innovation systems and adoption of indigenous production systems in AKST are dependent on the effectiveness of coordination among stakeholders involved in natural resources management, production, consumption and marketing e.g. farmers, extension, research, traders (Moustier et al., 2006; Temple et al., 2006). Failure to recognize this leads to poor adoption potential of the research outputs (Röling, 1988; World Bank 2007c). Scaling-up requires articulation between stakeholders acting at multiple levels of organizational from the farmer to international organizations and markets (Caron et al., 1996; Lele, 2004). AST can contribute by identifying the coordination processes involved in scaling-up, but this is now recognized to involve more than the typical micro-macro analysis of academic disciplines. AST also contributes to understanding coordination mechanisms supporting change, adaptation and technological innovation, through approaches that connect experimental / non-experimental disciplines, basic / applied research, and especially, technical, organizational, and economic variables (Griffon, 1994; Cerf et al., 2000).

3.2.4.1 Coordination and partnership toward greater collective interest

AKST affects sustainability through collective action and partnership with new stakeholders (e.g. agroforestry sector) that strengthen farmer organizations and their ability to liaise with policy-makers, and support the design of new organizations (e.g. water users associations).

**Major social, economic and political changes in agricultural and rural development have emerged in the last two decades through the involvement of new civil society actors.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| S | B | 0 to +2 | G | Wide applicability |

Since the 1980s, civil society actors (NGO, farmer and rural organizations, etc.) have become increasingly active in national and international policy negotiations (Pesche, 2004). The emergence of new rural organizations and civil society intermediaries coincides with the trend towards decentralization (Mercoiret et al., 1997ab). More recently, federated regional civil society organizations have emerged (Touzard and Drapieri, 2003). In 2000, ROPPA (Réseau des organisations paysannes et des producteurs d'Afrique de l'Ouest) was created in West Africa, under the umbrella of UEMOA (Union Economique et Monétaire Ouest-Africaine). Similarly, in South America, Coprofam (Coordenadora de Organizaciones de Productores Familiares del Mercosur) was created at the time of the implementation of the Mercosur mechanisms, in order to defend family agriculture.

**Farmer organizations representing a large number of poor agricultural producers have had great impact on rural livelihoods through the provision of services.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S, D | C | 0 to +3 | G | Wide applicability |

Farmer organizations have enlarged their activities from enhanced production to many other support functions, and not all are for profit (Bosc et al., 2002). The support includes coordination, political representation and defense of interests, literacy and other training, and cultivation methods for sustainability of production systems and social services. In some cases, these farmer organizations have taken direct responsibility for research and dissemination (as in the Coffee Producer Federation of Colombia).

**Access to water resources has been improved by water user associations and organizations ensuring access to water rights through user-based, agency and market allocations.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | B | 0 to +3 | G | Mainly in tropical countries |

Dissatisfaction with performance of government managed irrigation has led to the promotion of participatory irrigation management over the past twenty years. However, problems remain with efficiency of operations, maintenance, sustainability and financial capacity. The involvement of private sector investors and managers is gaining credibility as a way to enhance management skills, and relieve the government of fiscal and administrative burdens (World Bank, 2007a). Water User Association (WUA) schemes in several states in India (Rajasthan, Andhra Pradesh, Karnataka, West Bengal, Uttar Pradesh) have improved access to water resources and increased production through increased irrigation. Likewise, in Mexico, Turkey and Nepal, transferring irrigation management to farmers has resulted in improved operation, better maintenance of infrastructure, reduced government expenditure, and increased production (World Bank, 1999). In many countries, this evolution has also raised new questions regarding sustainability and social justice (Hammani et al., 2005; Richard-Ferroudji et al., 2006).

3.2.4.2 Markets, entrepreneurship, value addition and regulation

The outcomes and efficiency of market rules and organizations directly affect sustainability. Efficient trading involves (i) farmers acting within an active chain of agricultural production and marketing; (ii) dynamic links to social, economic and environmental activities in the region; (iii) development plans appropriate to heterogeneity of agriculture among countries; and (iv) recognition of the differences in farming methods and cultural background. Many farmers have a good understanding of the nature of the demand in terms of its implications for varieties, timing, packaging and permitted chemicals. As a result of knowledge-based approaches, they progressively modify their production practices and their portfolio of products in response to changing patterns of demand. The implementation of new norms regarding the use of AKST modifies market rules and organizations and differentially affects rural livelihoods, depending on local conditions.

**Both locally and internationally the food sector is processing a wider range of tropical products.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, D | B | 0 to +3 | G | Wide applicability |

Many different products can be processed from a single crop, e.g., maize in Benin is processed into forty different products, in large part explaining the limited penetration of imported rice and wheat into Benin. The branding of products by area of origin is becoming an important marketing tool affecting the competitiveness of local products in the tropical food sector (Daviron and Ponte, 2005; van de Kop et al., 2006). Competitiveness in the international market involves the promotion of distinctive properties of tropical foodstuffs (e.g. color, flavor,) in products such as roots and tubers.,

**In aquaculture, there is increased coordination of private sector-led production and processing chains.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | B | 0 to +2 | G | Wide applicability |

Formal and informal links between small-scale producers and large processing companies are contributing to more efficient and competitive aquaculture (shrimp, Vietnamese catfish, African catfish and tilapia), resulting in better quality for consumers, and secured margins for producers (Kumaran et al., 2003; Li, 2003). Export certification schemes are further streamlining production, processing, distribution and retail chains (Ponte, 2006).

**Seasonal fluctuation in fruit and vegetable supplies is a major problem in the marketing of perishable products.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | -3 to +1 | G | Wide applicability |

Various approaches have been developed to reduce the impacts of seasonality. For example, market-based risk management instruments have been instituted, such as the promotion of the cold-storage, insurance against weather-induced damage and encouragement of over-the-counter forward contracts (Byerlee et al., 2006). Initiatives like these are enhanced by the development of varieties and production technologies that expand the productive season and overcome the biotic and abiotic stresses, which occur during the off-season (Tchoundjeu et al., 2006).

**Consumers' concerns about food safety are affecting international trade regulations.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, D | C | 0 to +3 | R | Wide applicability |

The effects of the implementation of food safety standards on global trade is valued at billions of US dollars (Otsuki et al., 2001; Wilson and Otsuki, 2001). However, the regulatory environment for food safety can be seen as an opportunity to gain secure and stable access to affluent and remunerative new markets, and generate large value addition activities in developing countries (World Bank, 2005b).

**Food standards are increasingly important and have implications for consumer organizations and private firms.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +3 | G | Wide applicability |

New instruments of protection and competitiveness have emerged as 'standards' and new forms of coordination between actors in the food chain have been developed in response to consumer and citizen concerns. Actors in the food chain work together to specify acceptable production conditions and impose them on suppliers (Gereffi and Kaplinsky, 2001; Daviron and Gibbon, 2002). Initially limited to some companies, standards are becoming accepted globally (e.g. Global Standard Food [GSF], International Food Standard [IFS], GFSI [Global Food Safety Initiative], FLO [Fair Trade Labeling Organization] (JRC, 2007). The multiplication of these standards, which are supposed to improve food safety, preserve the environment, and reduce social disparities, etc., raises questions about international regulation, coordination, and evaluation (in the case of forests, Gueneau, 2006).

**Food labeled as 'organic' or 'certified organic' is governed by a set of rules and limits, usually enforced by inspection and certification mechanisms known as 'guarantee systems'.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, E, S, D | A | +1 to +3 | G | Wide applicability |

With very few exceptions, synthetic pesticides, mineral fertilizers, synthetic preservatives, pharmaceuticals, sewage sludge, genetically modified organisms and irradiation are prohibited in all organic standards. Sixty mostly industrialized countries currently have national organic standards as well as hundreds of private organic standards worldwide (FAO/ITC/CTA, 2001; IFOAM, 2003, 2006). Regulatory systems for organics usually consist of producers, inspection bodies, an accreditation body for approval and system supervision and a labeling body to inform the consumer (UN, 2006b). There are numerous informal organic regulation systems outside of the formal organic certification and marketing systems. These are often called "peer" or "participatory" models. They do not involve third-party inspection and often focus on local markets (UN, 2006b). The IFOAM and CODEX guidelines provide consumer and producer protection from misleading claims and guide governments in setting organic standards in organic agriculture (see 3.2.2.1.9). The cultivation of GMO crops near organic crops can threaten organic certification due to the risk of cross-pollination and genetic drift.

**Some food standards are now imposing minimum conditions of employment.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, D | C | -3 to +2 | G | Wide applicability |

To face the inequalities that accrue from benefits to large-scale producers, standards have been developed to encourage small-scale producers. The most prominent example is the Fair Trade Movement (www.fairtrade.org.uk), which aims to ensure that poor farmers are adequately rewarded for the crops they produce. In 2002 the global fair trade market was conservatively estimated at US $500 million (Moore, 2004). This support has helped small organizations to market their produce directly by working similarly to that of forest certification. Where foreign buyers impose labor standards, the terms and conditions of employment in the formal supply chains are better than in the informal sector. Enforcement of food standards furthermore improve the working environment and ensure that agricultural workers are not exposed to unhealthy production practices.

**The globalization of trade in agricultural products is not an import-export food model that addresses poverty and hunger in developing countries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, D | C | -4 to 0 | G | Wide applicability |

Many complex factors affect the economy of a country. The following evidence suggests that international policies that promote economic growth through agriculture do not necessarily resolve the issue of poverty (Boussard et al., 2006; Chabe-Ferret et al., 2006):

- An estimated 43% of the rural population of Thailand now lives below the poverty line even though agricultural exports grew 65% between 1985 and 1995.
- In Bolivia, after a period of spectacular agricultural export growth, 95% of the rural population earned less than a dollar a day.
- The Chinese government estimates that 10 million farmers will be displaced by China's implementation of WTO rules, with the livelihoods of another 200 million small-scale farmers expected to decline as a result of further implementations of trade liberalization and agriculture industrialization.
- Kenya, which was self-sufficient in food until the 1980s, now imports 80% of its food, while 80% of its exports are agricultural.
- In the USA net farm income was 16% below average between 1990-1995, while 38,000 small farms went out of business between 1995-2000.
- In Canada, farm debt has nearly doubled since the 1989 Canada-U.S. Free Trade Agreement.
- The U.K. lost 60,000 farmers and farm workers between 98-2001 and farm income declined 71% between 1995-2001.

To provide clearer and broader figures, the World Bank has implemented the Ruralstruc project to assess the impact of liberalization and structural adjustment strategies on rural livelihoods (Losch, 2007). These examples indicate that poverty alleviation requires more than economic policies that aim at promoting global trade.

**The globalization of the food supply chain has raised consumer concerns for food safety and quality.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | -3 to 0 | G | Wide applicability |

The incidence of food safety hazards such as: 'mad cow disease' (bovine spongiform encephalopathy), contamination of fresh and processed foods (e.g. baby milk, hormones in veal, food colorings and ionized foodstuffs in Europe, mercury in fish in Asia, etc.) have resulted in the emergence of traceability as a key issue for policy and scientific research in food quality and safety. Over the past ten years considerable research effort has been directed towards assessing risks and providing controls (Hazard Analysis Critical Control Point - HACCP). These have included the implementation of food traceability systems complying with marketing requirements (Opara and Mazaud, 2001). Consumer concerns about the safety of conventional foods and industrial agriculture as result of the use of growth-stimulating substances, GM food, dioxincontaminated food and livestock epidemics, such as outbreaks of foot and mouth disease, have contributed to the growth in demand for organic food. Many consumers perceive organic products as safer and of higher quality than conventional ones. These perceptions, rather than science, drive the market (http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3).

**'Enlightened Globalization' is a concept to address needs of the poor and the global environment and promote democracy.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S, D | D | Not yet known | G | Wide applicability |

The concept of Enlightened Globalization has been proposed to address "the needs of the poorest of the poor, the global environment, and the spread of democracy" (Sachs, 2005). It is focused on "a globalization of democracies, multilateralism, science and technology, and a global economic system designed to meet human needs". In this initiative, international agencies and countries of the industrial North would work with partners in the South to honor their commitments to international policies and develop new processing industries focused on the needs of local people in developing countries while expanding developing economies. Enlightened Globalization also is aimed at helping poor countries to gain access to the markets of richer countries, instead of blocking trade and investment.

**There is new and increasing involvement of the corporate sector in agroforestry.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | C | 0 to +2 | R | Wide applicability |

Typically, multinational companies have pursued large-scale, high input monocultures as their production systems. However, a small number of multinational companies are now recognizing the social, environmental, and even economic, benefits of community engagement and becoming involved in agroforestry to develop new crop plants that meet specific needs in a diversifying economy. There are now several examples of new niche products becoming new international commodities (Mitschein and Miranda, 1998; Wynberg et al., 2002; Tchoundjeu et al., 2006). In Brazil, DaimlerChrysler has promoted community agroforestry for the production of a range of raw plant materials used to make a natural product alternative to fiberglass in car manufacture (Mitschein and Miranda, 1998; Panik, 1998), while in Ghana, Unilever is developing new cash crops like *Allanblackia* sp. as shade trees for cocoa (IUCN, 2004; Attipoe et al., 2006). In South Africa, the '*Amarula'* liqueur factory of Distell Corporation buys raw *Sclerocarya birrea* fruits from local communities (Wynberg et al., 2003). New public/private partnerships such as those developed by the cocoa industry, can set the standard for the integration of science, public policy and business best practices (Shapiro and Rosenquist, 2004).

### 3.2.4.3 Policy design and implementation

Policy instruments can be introduced at many different levels: sectorial, territorial, international science policies, and international policies, treaties and conventions.

**Analyses reveal that the Green Revolution was most successful when the dissemination of AKST was accompanied by policy reforms.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +2 | R | Wide applicability |

Policy reform has been shown to be particularly important for the successful adoption of Green Revolution rice production technologies in Asia. When Indonesia, implemented relevant price, input, credit, extension and irrigation policies to facilitate the dissemination of the cultivation of potentially high-yielding, dwarf varieties, physical yields increased by a factor of 4-5 per unit area, as well as achieving very significant increases in labor productivity and rural employment (Trebuil and Hossain, 2004). Likewise, in Vietnam, increased rice production in the Mekong delta in 1988 was associated with the implementation of similar policies (Le Coq and Trebuil, 2005).

**Agricultural policies that in the past gave inadequate attention to the needs of small-scale farmers and the rural poor are now being replaced by a stronger focus on livelihoods.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L | B | -3 to +3 | G | Wide applicability |

Agricultural policy over the last 50 years focused on the production of agricultural commodities and meeting the immediate staple food needs to avoid starvation in the growing world population (Tribe, 1994), and rarely explicitly targeted the multiple needs of the rural population (World Bank, 2007a). This situation has changed over the last 10 years with the development of a livelihoods focus in rural development projects, but in many countries, national policies are still focused on high-input farming systems with a strong emphasis on intensive farming that differs from the small-scale, low-input, mixed cropping systems of small-scale farmers which may be hurt by untargeted policy reforms (OECD, 2005). A stronger livelihood approach is based on sustainability issues, diversification of benefits, better use of natural resources, ethical trade and a more people-centric focus. Diversified farming systems often mimic natural ecosystems as noted in best-bet alternatives to slash-and-burn (Palm et al., 2005b). These typically provide radical improvements in farmer livelihoods (Vosti et al., 2005) and environmental benefits (Tomich et al., 2005).

**Organizations that support and regulate the production of agricultural crops, livestock, fisheries and forestry are often poorly interconnected at the national and international level, and are also poorly connected with those responsible for the environment and conservation.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | -3 to 0 | G | Wide applicability |

The creation of synergies between increased production and development and sustainability goals are often limited by the ‘disconnects’ between agriculture and the environment. Thus the ideal of sustainable land use is often more a subject of political rhetoric than government policy. However, there are signs that some of the INRM initiatives – in agroforestry, organic agriculture, sustainable forestry certification, etc – are starting to influence environmental land use planning and agricultural authorities (Abbott et al., 1999; Dalal-Clayton and Bass, 2002; Dalal-Cayton et al., 2003), as they are also in fisheries (Sanchirico et al., 2006).

**In the agricultural and food sectors, coordination of the development of international policies created by the WTO have strongly interacted with global AKST actors.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | C | -1 to +2 | G | Wide applicability |

Changes during the period of structural adjustment had considerable impact on the ability of developing countries to define targets and find the means to implement their public research and policy interventions. The need for more "policy space" is now widely acknowledged (Rodrik, 2007), creating a wide gap between the demand for policy and the implementation of either new policy or public/private stakeholder initiatives (Daviron et al., 2004). It is not clear whether the centralized and public AST policies of the last century can be replaced by modern decentralized public/private partnerships (such as private investment on R&D, standardization initiatives, third-party certification and farmer organization credit and saving programs) targeting the reduction of poverty and increased sustainability.

*3.2.4.3.1 Sectoral policies*

Many of the different sectors encompassed by agriculture have policies which specifically address a particular production system, target population, or natural resource. Likewise, specific agricultural policies concern food safety and health issues. This can create problems, as these different sectors of agriculture are often poorly integrated, or even disconnected. However, a few examples (e.g. agroforestry and forestry) are emerging which illustrate some convergence between sectors.

**One of the consequences of structural adjustment policies has been the abandonment of the land by poor farmers, who can no longer afford farm inputs.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L | B | -4 to 0 | G | Mainly small-scale agriculture |

Rising input prices have resulted in high migration from the countryside to urban centers in search of jobs; often low paid manufacturing jobs. In India, for example, the numbers of landless rural farmers increased from 27.9 to over 50 million between 1951 and the 1990s, hampering economic growth. This illustrates that achieving higher aggregate economic growth is only one element of an effective strategy for poverty reduction (Datt and Ravallion, 2002) and that redressing existing inequalities in human resource development and between rural and urban areas are other important elements of success.

**Although governments have expanded their role in water management, particularly in large scale irrigation schemes, sustainability requires effective institutional arrangements for the management of the resource and particularly public-private coordination.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | -2 to +2 | G | Wide applicability |

Large dams, reservoirs and irrigation systems have usually been built by government agencies for economic development, including agriculture, urbanization and power generation. In most countries, agriculture has been by far the largest user of water and typically its allocation and management has been a public concern of government (de Sherbinin and Dompka, 1998). In the 1980's dissatisfaction with irrigation management and sustainability was common and the importance of empowering farmers, together with their traditional systems of water rights, was recognized as important. This led to the concept of participatory irrigation management in the 1990s. Nevertheless, communities of water users have faced numerous challenges in gaining sustainable and equitable access to water (Bruns and Meinzen-Dick, 2000; Meinzen-Dick and Pradhan, 2002). Water User Associations (WUA) have emerged as an effective way of managing water delivery (Abernethy, 2003; Schlager, 2003). This approach, as well as the rise of the private sector, has led to the redefinition of the role of governments over the past 20 years. Governments are now viewed as facilitators of investments, regulators of this sector and responsible for sustainable management at the watershed scale (Hamann and O'Riordan, 2000; Perret, 2002; ComMod Group, 2004).

**Deforestation is often an outcome of poorly linked inter-sectorial policies.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, L, E, S | B | +1 to +4 | R | Mainly small-scale agriculture |

One of the common and dominant outcomes from an international study of slash-and-burn agriculture was that small-scale farmers cut down tropical forests because current national and international policies, market conditions, and institutional arrangements either provide them with incentives for doing so, or do not provide them with alternatives (Palm et al., 2005b; Chomitz et al., 2006). This trend will continue if tangible incentives that meet the needs and needs of local people for more sustainable alternatives to slash-and-burn farming are not introduced. Some options linked to the delivery of international public goods and services, like carbon storage, may be very expensive (Palm et al., 2005a), while others like the participatory domestication of trees providing both environmental services and marketable, traditional foods and medicines (Tchoundjeu et al., 2006), that help farmers to help themselves may be a cheaper option (see *3.2.2.1.6*).

**Integrating forestry with other land uses has economic, environmental and social benefits.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S, D | C | 0 to +3 | G | Wide applicability |

Recently forest agencies have recognized that tree cover outside public forests and in farmland are important for national forest-related objectives (FAO, 2006b). In forest certification the links between civil society and market action have been a key driver in the social integration of intensive forest plantations (Forest Stewardship Council www.fsc.org and Pan-European Forest Certification www.pefc.org). Consequently, certification standards are improving the direction of both forest policy and forest KST at national and international levels (Bass et al., 2001; Gueneau and Bass, 2005). Forest certification is linking land use issues from the tree stand, to the landscape, and ultimately to global levels for the production of sustainable non-timber benefits and environmental services (Pagiola et al., 2002; Belcher 2003). When KST and market conditions are right, the flow of financial benefits can make multipurpose forest systems economically superior to conventional timber-focused systems (Pagiola et al., 2002). Non-wood forest products produce a global value of at least $4.7 billion in 2005 (FAO, 2005b).

**Public interest in food safety has increased and food standards have been developed to ensure that the necessary safety characteristics are achieved.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +2 | G | Wide applicability |

Public interest in the chemical residues in fresh produce (Bracket, 1999; Kitinoja and Gorny, 1999) has been heightened by the provision of quantitative data on chemical use in agriculture (OECD, 1997; Timothy et al., 2004), especially the use of banned pesticides in developing country agriculture. Of special concern is the permitted thresholds of heavy metals (Mansour, 2004), and their status as contaminants, especially as food administrators in developed countries have tended to set increasingly lower levels of tolerance. Traceability has become an important criterion of food quality (Bureau et al., 2001). Internationally recognized food safety standards include GAP, GMP like ISO 9000, EUREP GAP, HACCP. Similarly, various measures and standards have been developed for food quality including Diet Quality Index (Patterson et al., 1994), Analysis of Core Foods (Kristal et al., 1990), and Healthy Eating Index (Kennedy et al., 1995). Dietary Diversity Scores are also now increasingly used to measure food quality (Kant et al., 1993 and 1995; Hatloy, et al., 1998; Marshall et al., 2001; Ali and Farooq, 2004), while total nutritive values are being used to prioritize food commodities (Ali and Tsou, 2000). Although consumers benefit from the better quality and greater safety attributes of food products, the enforcement of food quality standards also may increase food prices **(**Padilla, 1992). In addition, the cost of applying food safety standards can be a drain on public resources or may lead to disguised protection, as in the case of 'voluntary certifications' which are increasingly a prerequisite for European retailers (Bureau and Matthews, 2005).

**GMOs are experiencing adoption difficulties in Europe.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | -2 to -4 | G | Wide applicability |

GM crops are only grown commercially in 3-4 European countries, (primarily Spain) (James, 2006) and very few GM crops and foods have been approved for commercialization. Rejection by consumers, food companies and supermarkets is responsible for poor adoption and can taken as an indication that consumer demand for GM products is almost non-existent (Bernauer, 2003). However, it is unclear to what extent consumer demand has been the result of EU regulations or *vice versa* and debate continues about the level of appropriate regulations. Before the mid-1980s, there were no GMOs on the market in Europe, but since then the EU has adopted regulations on the approval of GM crops and foods. The strict labeling laws have resulted in very few GM foods sold on the European market. There is however more tolerance of non-food GM crops in Europe and recent reports indicate that some 75% of cotton imported into the EU today is from GM varieties, mainly from the USA and China. In other parts of the world the situation with GM foods is very different, Fifteen of 16 commercial crops in China have genetically engineered pest resistance (8/16 virus, 4/16 insect, 4/16 disease resistance) and herbicide resistance (2/16) ( See 3.2.1.4).

**Adoption of GMOs has had some serious negative economic impacts in Canada and USA.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | B | -3 to -4 | G | Wide applicability |

After the adoption of GM varieties, Canadian farmers lost their market for $300 million of canola (oilseed rape) to GMO-free markets in Europe (Freese and Schubert, 2004; Shiva et al., 2004). Likewise, after leading US food allergists judged Bt-corn to be a potential health hazard (Freese, 2001), US $1 billion worth of product recalls followed the discovery of animal feed Bt-corn in products for human consumption (Shiva et al., 2004). Maize exports from USA to Europe have also declined from 3.3 million tonnes in 1995 to 25,000 tonnes in 2002 due to fears about GMOs (Shiva et al., 2004). The American Farm Bureau estimates this loss has cost US farmers $300 million per year (Center for Food Safety, 2006).

*3.2.4.3.2 Territorial policies*

**Attention to the livelihood needs of small-scale farmers and the rural poor has been insufficient, but now many developing nations are implementing policies to enhance incomes and reduce poverty.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| L, D | B | -2 to +3 | G | Wide applicability |

Improving the livelihood of small-scale farmers has typically focused on market participation, through better access to information, increased efficiency of input supply systems, provision of credit, and better market chains and infrastructure (Sautier and Bienabe, 2005). In some countries, agricultural policies and market liberalization have increased economic differentiation among communities and households (Mazoyer and Roudart, 2002; IFAD, 2003). Small-scale, low-input agriculture systems have an important role as a social safety net (Perret et al., 2003), help to maintain cultural and community integrity, promote biodiversity and landscape conservation. However, the impacts of these commercialization policies on social conflict, land ownership, kinship, and resource distribution are not usually assessed (Le Billon, 2001).

**Policy responses have been developed to enhance food and nutritional security, and food safety, and to alleviate the impacts of seasonal fluctuations on the poor.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | B | 0 to +3 | G | Wide applicability |

Responses to food and nutritional insecurity have included the provision of infrastructure for health facilities and parental education (Cebu Study Team, 1992; Alderman and Garcia 1994); programs ensuring equitable distribution of nutritious foods among family members; regulations to enforce the provision by retailers of nutritional information on food purchases (Herrman and

Roeder, 1998), and the improvement of safety practices for those preparing, serving and storing food (Black et al., 1982; Stanton and Clemens, 1987; Henry et al., 1990). Other approaches to supporting marketing have included linking the domestic and international markets through involvement of the private sector, developing food aid, food-for-work programs, and price instability coping mechanisms (Boussard et al., 2005).

**National conservation and development strategies have increasingly promoted more integration of sustainability goals at local and national levels.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S, D | B | 0 to +3 | G | Wide applicability |

National conservation and development strategies have recently gained as much political profile as land use planning in the past. National poverty reduction strategies, conservation strategies, and sustainable development strategies form a pool of cross-cutting approaches that seek to link institutions. This has involved the engagement of local stakeholders in participatory processes to negotiate broad visions of the future, and to focus local, regional and national institutions on:- poverty reduction, environmental sustainability (Tubiana, 2000), sustainable development (Dalal-Clayton and Bass, 2002) and participatory agroenterprise development (Ferris et al., 2006).

**Government ministries and international agencies responsible for agriculture, livestock, fisheries and food crops are typically disconnected and in competition for resources, and power**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S, D | C | -3 to 0 | G | Wide applicability |

In many countries around the world the disconnections between the various subsectors of agriculture place them in competition for resources and power. Consequently, lack of compatibility between the policies and laws of tdifferent sectors make it difficult to promote sustainable development, as the potential synergies are lost, e.g. promoting forest removal for farmers to secure agricultural land tenure and grants (Angelsen and Kaimowitz, 2001). To address this problem, cross-sectoral national forums associated with international agreements/summits, have developed strategic planning initiatives to provide an integrated framework for sustainable development and poverty reduction, with mixed results. For example, the Action Plans of the Rio Earth Summit (www.un.org/esa/sustdev/documents/agenda21) and the World Summit on Sustainable Development (2002) put a premium on national level planning as a means to integrate economic, social and environmental objectives in development (Dalal-Clayton and Bass, 2002). These Action Plans have been most successful where they have i) involved multistakeholder fora; consulted 'vertically' to grass-roots as well as 'horizontally' between sectors; focused on different sectors' contributions to defined development and sustainability outcomes (rather than assuming sector roles); ii) been driven by high-level and 'neutral' government bodies, and iii) been linked to expenditure reviews and budgets (Dalal-Clayton and Bass, 2002; Assey et al., 2007). In most countries the importance of farming for both economic growth and social safety nets is clear in such strategies, but few have stressed the links with forestry. However, due to lack of updated information, it has been difficult to progress beyond a broad, consultative approach and to identify specific tradeoff decisions, especially concerning environmental issues (Bojo and Reddy, 2003).

*3.2.4.3.3 Scientific policies*

Scientific policies shape the design and the use of AKST and subsequently, its impact on development, in various ways. Examples include the organization of disciplines within academic and AKST institutions, and the implementation of specific policies on intellectual property rights.

**Typically, AKST development has rationalized production according to academic discipline, constraining the development of integrated production systems.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | C | -3 to +1 | G | Wide applicability |

In the past, crop, livestock and forest sciences have typically been implemented separately. However, agroforestry integrates trees with food crops and/or livestock in a single system, improving the relationships between food crops, livestock and tree crops for timber or other products, but this level of integration is rarely visible in international institutions, national governments and markets. For example, the World Commission on Forests and Sustainable Development (1999), and the Intergovernmental Panel on Forests do not focus on agricultural links. Likewise, the InterAcademy Council Report on African Agriculture (2004) paid scant attention to forestry, or even to agroforestry. However, this is changing and a few new forms of local organization and collective action are emerging, such as Landcare (www.landcare.org), Ecoagriculture (McNeely and Scherr, 2003); community forestry associations (Molnar, et al. 2005), and biological corridor conservation projects. This change has just emerged at the policy level, with the European Union approving a measure entitled “First establishment of agroforestry systems on agricultural land” (Article 44 of Regulation No 1698/2005 and Article 32 Regulation No 1974/2006 - Annex II, point 5.3.2.2.2) in 2007 to provide funds for the establishment of two agroforestry systems in mainland Greece.

**IPR policies are used to protect plant genetic resources that are important for food and agriculture.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | C | -3 to +3 | G | Wide applicability |

Most developed countries have a system to register Plant Breeders Rights, often supported by Trade Marks and Patents. These schemes are genuinely fostering innovation and conferring benefits to innovators, while also protecting genetic resources. They are supported by the International Treaty on Plant Genetic Resources for Food and Agriculture (TRIPS) and the Convention on Biological Diversity (UNEP, 1993) which aim to promote both the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use (FAO, 2001, 2002b). The treaty addresses the exchange of germplasm between countries and required all member countries of World Trade Organization to implement an Intellectual Property Rights (IPR) system before 2000 (Tirole et al., 2003; Trommetter, 2005) "for the protection of plant varieties by patents or by an effective *sui generis* system" (Mortureux, 1999; Célarier and Marie-Vivien 2001; Feyt, 2001). Germplasm arising from international public-funded research is protected on behalf of humankind by the FAO (Frison et al., 1998; Jarvis et al., 2000; Sauvé and Watts, 2003). Agriculture is being integrated into the program and work of the CBD, including conservation of domesticated species, genetic diversity and goals for conservation of wild flora and agricultural landscapes.

**Intellectual property rights regulatory frameworks currently do not protect the innovations or rights of communities or farmers in developing countries to their indigenous genetic resources.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | B | 0 to +3 | G | Wide applicability |

The development IPR frameworks at international and national scales, through patents, trade marks, contracts, GI, varieties do not offer much protection for poor farmers and there are many unresolved issues. For example, in developing countries many farmers do not have the ability or income to protect their rights, and the identification of the innovator can be controversial. Consequently much international activity by NGOs and farmer organizations is focused on trying to develop effective protection mechanisms for farmers and local communities based on traceability and transparency (Bazile, 2006), as for example in the Solomon Islands (Sanderson and Sherman, 2004). This is important to prevent biopiracy and to promote legitimate biodiscovery that meets internationally approved standards.

**To assess and manage potential risks from LMOs and GMOs, governments are developing National Biosafety Frameworks.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| H, L, E, S | C | Not yet known | G | Worldwide |

Countries need to have capacity and mechanisms to make informed decisions as they accept or reject products of modern biotechnology (Pinstrup-Andersen and Schioler, 2001). Currently many Governments, including eighty developing countries, have developed National Biosafety Frameworks (NBF) to support the application and use of modern biotechnology in accordance with national policies, laws and international obligations, in particular the Cartagena Protocol on Biosafety (CBD, 2000). This is the first step towards the development of improved capacity for biosafety assessment and implementation of the Cartagena Protocol under the UNEP-GEF Biosafety Project (http://www.unep.ch/biosafety/news.htm). NBFs have had some success but they have not always been adopted by governments. Many African countries still lack biosafety policies and regulations and technical enforcement capacity.

*3.2.4.3.4 International policy, treaties and conventions*

**The globalization process has been supported by international and regional trade policy frameworks, and by the policy recommendations (structural adjustment programs) of the World Bank and International Monetary Fund.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | A | -2 to +2 | G | Wide applicability |

There are links between global trade and economic agreements and institutions, such as the World Trade Organization (WTO) and Regional Trade Agreements (e.g. NAFTA, EPA), IMF, bi-lateral agreements, and domestic and regional agricultural policies, technologies, R&D and natural resource use. AKST played a role in this process, particularly neo-classical economic theory which emphasized the need to shift resources in line with comparative advantages at national level, and restore price incentives to generate income at local level. Assessment of the impact of market-oriented policies has demonstrated the need for complimentary and supportive public policies to cope with some of the unsustainable impacts of globalization and to reinforce the need for greater sustainability of development and growth (Stiglitz, 2002).

**Development microeconomics, and agricultural economics of international markets have called for *sui generis* policies**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S, D | D | 0 to +3 | G | Wide applicability |

Two approaches have been taken to development economics research and policy. Firstly, there has been a shift of focus from macro issues to micro problems; e.g. from markets to households, from products to people (Sadoulet et al., 2001; Banerjee and Duflo, 2005). In this approach, research on the impacts of risk and imperfect information at the household level provided insights on the cost of market failure for households and countries (Rothschild and Stiglitz, 1976; Newberry and Stiglitz, 1979; Binswanger, 1981; Stiglitz, 1987; Boussard et al., 2006). For example, local market and institutional conditions were found to determine the success or failure of public policy. In China and other emerging economies *sui generis* macro policies have outperformed the so-called “Washington consensus” policies (Santiso, 2006). This is increasing interest in *sui generis* development and trade policies (Stiglitz and Greenwald, 2006; Rodrik, 2007). In the second approach, agricultural economics research continues to explore the value and power distribution along international commodity market chains (Gereffi and Korzeniewicz, 1994; Daviron and Ponte, 2005; Gibbons and Ponte, 2005), to determine how new patterns of labor organization throughout the chain have impact upon its overall function – and notably how they affect farmer income.

**The World Trade Organization (WTO) has greatly expanded the scope of trade and commodity agreements as set out in the General Agreements on Tariffs and Trade (GATT).**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | C | -3 to +2 | G | Wide applicability |

Agricultural economic research on the causes and consequences of market instability on people and national economies (e.g. Schultz, 1949) shaped the post-war development of developing countries policies prior to Independence. These policies led to new institutional schemes to address development issues, e.g. the creation of UNCTAD and the formulation of special arrangements under GATT in the 1970s, such as the definition of rules with regard to setting trade quotas and tariffs (Ribier and Tubianz, 1996). Other matters have remained under the purview of national governments. Although not without flaws, this system has provided tools such as trade barriers which allow countries to protect their domestic markets. The Uruguay Round of negotiations, which led to the creation of the WTO, greatly expanded the power of international arenas over agriculture, limiting the authority of national governments to fixed policies governing their own farmers, consumers, and natural resources (Voituriez, 2005). The impacts of these WTO policies on the agricultural sector have been controversial. *Ex post* analysis indicates negative impacts on the lives of poor food producers and indigenous peoples, while *ex ante* analysis on current Doha Scenarios point to possible welfare losses in the short term for some poor countries and poor households (Hertel and Winters, 2005; Polaski, 2006). Some of the losers from trade liberalization are also among the poorest (Chabe-Ferret et al., 2006). Similarly, traditional small scale farming and fishing communities worldwide have suffered from globalization, which has systematically removed restrictions and support mechanisms protecting them from the competition of highly productive or subsidized producers. To redress these negative impacts, current AKST initiatives include the examination of: i) broader special and differential treatment for developing countries, allowing them to experiment with *ad hoc* policy within a wider policy space and ii) the resort to special "rights" – e.g. the Right to food or 'Food Sovereignty' under UN auspices (Ziegler, 2003).

**Regional Trade Agreements have had major impacts on food exports and agriculture systems in some countries.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | C | -3 to +2 | R | North and South America |

The implementation of North American Free Trade Agreement **(**NAFTA) has had major social and economic impacts on agriculture and the trading of food. For example, while beneficial to USA, corn production in Mexico collapsed with an associated decline in the real rural wage (Hufbauer and Schott, 2005). This situation arose because as a condition for joining NAFTA, Mexico had to change its Constitution and revoke the traditional 'ejido' laws of communal land and resource ownership, and dismantle its system of maintaining a guaranteed floor price for corn, which sustained more than 3 million corn producers. Within a year, production of Mexican corn and other basic grains fell by half and millions of peasant farmers lost their income and livelihoods. Many of these farmers are part of the record-high number of immigrants crossing U.S. borders.

**One of the side effects of the increased food trade has been worldwide increase in the number of food and food-borne diseases.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N | C | -3 to 0 | G | Wide applicability |

The World Health Organization (WHO) has identified that the increased trade of food has contributed to increased levels of human illness worldwide. In part this may simply be due to the increased volume of food imports. The WTO's Sanitary and Phytosanitary Agreement (SPS) has set criteria for member nations to follow regarding their domestic trade. These policies affect food safety risks arising from additives, contaminants, toxins, veterinary drug and pesticide residues or other disease-causing organisms. The primary goal of the SPS is to facilitate trade by eliminating differences above and below SPS standards in food, animal, and plant regulations from country to country. Independently from the international standard (Codex Alimentarius, www.codexalimentarius.net), national standards might imply an asymmetry of trade exchanges.

**Structural adjustment policies (SAPs) of the World Bank and the International Monetary Fund (IMF) have significantly re-shaped national agriculture policies in developing countries**.

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| D | B | -3 to +1 | G | Wide applicability |

The structural adjustment policies were aimed at helping countries cut down their debt. Many SAPs required developing countries to cut spending. As a result, centralized seed distribution programs; price supports for food and farm inputs; agricultural research, and certain commodities (often locally consumed foods) were eliminated or downsized (Bourguignon et al., 1991). While national support systems protecting traditional livelihoods (maintaining native crops, land races, etc.), food security, rural communities, and local cultures suffered, private corporations were given loans to partner with developing countries to develop industrial agriculture with crops mainly for export. Such financial mechanisms controversially promoted monocultural cropping that required farm inputs such as commercial seeds, chemicals, fossil-fuel based machinery, as well as requiring an increase in water usage.

**Rising environment concerns and the recognition of global environmental public goods have had impacts on trade and livelihoods.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E, S | C | -3 to +3 | G | Wide applicability |

Increased interest in tropical forest conservation and the potential role of marketing non-timber forest products has led to heightened interest in the international trade of a wide range of natural products (e.g. Kusters and Belcher, 2004; Sunderland and Ndoye, 2004). The Convention on Biological Diversity has brought attention to issues of access to, and use of genetic resources of a wide range of species not formerly considered as crops, but of significance in horticulture, biotechnology, crop protection and pharmaceutical/nutriceutical and cosmetics industries (ten Kate and Laird, 1999; Weber, 2005). The CBD also outlined the ways in which these industries should interact responsibly with traditional communities, the holders of Traditional Knowledge about products from this wide array of potentially useful species when engaging in 'biodiscovery' and 'bioprospecting' (Laird, 2002). In particular, it has highlighted the need to appreciate the interactions between nature conservation, sustainable use and social equity through the development of 'fair and equitable benefit sharing agreements' that respect the culture and traditions of indigenous people, and that support and enhance genetic diversity (Almekinders and de Boef, 2000).

3.2.4.4 Territorial governance

Territory is a new scale, intermediate between local and national issues, allowing market and state failures to be addressed. It is a portion of space delimitated by a social group that implements coordination institutions and rules and thus is useful when developing integrated approaches to rural development (Sepulveda et al., 2003; Caron, 2005). Applied to agricultural production, the concept helps to address disconnects between scales with regard to ecological processes, individual decisions, collective management and policies. As it is controlled by local stakeholders, it also strengthens participation in the design of new activities and policies to reduce or prevent marginalization.

**The concept of multifunctionality in agriculture and rural areas has simultaneously opened the way to changes in policies, research and operational issues.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | -5 to +5 | G | Worldwide |

Multifunctional agriculture became a new policy goal in Europe in 2000 (www.european-agenda.com), which encouraged the transformation of rural areas towards a 'multifunctional, sustainable and competitive agriculture throughout Europe'. The main idea was to encourage the production of non-commodity goods or services through the subsidy of commodity outputs (Guyomard et al., 2004). Promoting multifunctionality has sometimes been the milestone of new policies, such as the French 'Territorial Management Contract' (*Contrat Territorial d'Exploitation*, CTE) implemented through the 1999 Agricultural Act. The objectives have been partially achieved (Urbano and Vollet, 2005) in areas where the supply of high quality products has been increased through contracts between government and farmers, while protecting natural resources, biodiversity and landscapes. However, it is not limited to developed countries and in some developing countries, notably Brazil, multifunctional agriculture has promoted policies for family agriculture (Losch, 2004). Multifunctionality has also been advocated as a sustainable approach to land use in Africa (Leakey, 2001ab). In Europe, the concept of multifunctionality has progressed through state-of-the-art research projects (www.multagri.net), for example through new modeling tools to understand the integration of different functions.

**Multifunctional approaches of rural territories contribute to the evaluation of rural development practices in which agricultural and non-agricultural business come together.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | 0 to +4 | G | Wide applicability |

Rural development to reduce poverty and improve the rural environment is recognized as an integrated activity requiring policies that take into account the holistic nature of the task. Consequently, current approaches are maintaining a broad vision of agriculture that involves:

farmers integrated into the appropriate agricultural production-trade chain with dynamic links to social, economic and environmental activities in their region. Development plans are specific to the needs of the farmer and the rural development sector and recognize the heterogeneity of agriculture and its cultural setting, within and between countries (Sebillote, 2000; 2001)

**In Australia, multifunctionality has stimulated a debate about Globalized Productivism *versus* Land Stewardship.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, H, L, E, S, D | B | Not yet achieved | L | Wide applicability |

In Australia, the unsustainability of agriculture lies in the application of European type of farming systems in an environment to which they are inherently unsuited (Gray and Lawrence, 2001), and, in pursuit of market liberalism, the application of neoliberal policies targeting 'competitive' or 'globalized' productivism (Dibden and Cocklin, 2005). In this scenario, with the increasing influence of multinational agrifood companies, landholders are pressured to increase production and extract the greatest return from the land in a competitive marketplace in ways that do not reward environmental management (Dibden and Cocklin, 2005). To reverse the social, economic and environmental decline of Australian agriculture the Victorian government has discussed strategies with farmers for moving towards Land Stewardship. The outcome favored voluntary and education-based tools, over market-based instruments and saw command-and-control regulation as a last resort (Cocklin et al., 2006, 2007). In this debate, Land Stewardship was seen as a hybrid between the 'market-based instruments policy prescription' and a newer 'multifunctional approach', with the recognition that people are a vital element in the sustainability equation (Cocklin et al., 2006). Multifunctionality and Land Stewardship therefore emerge as strategies promising new income streams associated with the economic diversification of the enterprise, within a more spatially-variable rural space, founded on genuine social, economic and environmental integration.

**Participatory land use planning has recently re-emerged highlighting its political and economic nature and an increased concern with equity rather than just productivity.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| S, D | B | 0 to +2 | G | Wide applicability |

The disciplines of land use and rural planning now bring together the different sectors of the rural economy, especially farming, forestry and ecosystem conservation. Comparisons of actual land use with 'notional potential' derived from analysis of soils, vegetation, hydrology and climate, have been based on systems of resource survey and assessment (Dalal-Clayton et al., 2003). In the post-colonial era, these systems have tended to be technocratic tools used by centrally-planned economies, and development agencies that have played key roles in both the process of conversion of forest to farming, and the improvement of farm productivity (Dalal-Clayton et al., 2003); optimally at a watershed level or regional level. This hierarchical approach was not often recognized by stakeholders, especially politicians, and was neutral to all-important market influences (Dalal-Clayton et al., 2003). Consequently, land use planning has become: i) more decentralized, often being absorbed into district authorities, ii) more focused on processes of learning based on natural resource capabilities, rather than producing one-off master plans segregating different sectoral land uses, and iii) more based on participatory approaches to recognize the need for greater equity, to identify locally-desirable land use planning options and to improve commitment and 'ownership' (Caron, 2001, Lardon et al., 2001; Dalal-Clayton et al., 2003). These approaches have led to better national conservation and development strategies but they usually have major capacity constraints, which result in blunt sector-based plans and that do not realize all the potential synergies.

**Modeling water allocation at the territorial level contributes to a more efficient water management.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| E | B | 0 to +2 | G | Wide applicability |

Optimization economic models on water allocation among competing sectors for decision support have dominated the international literature for a long time (Weber, 2001; Salman et al., 2001; Firoozi and Merrifield, 2003). Recently, there have been an increasing number of studies adopting simulation and multi-objective frameworks. Examples include water allocation between irrigation and hydropower in North Eastern Spain (Bielsa and Duarte 2001), an economic optimization model for water resources planning in areas with irrigation systems (Reca et al., 2001), a multi-objective optimization model for water planning in the Aral Sea Basin which has uncertain water availability (McKinney and Cai, 1997), and water allocation to different user sectors from a single storage reservoir (Babel et al., 2005). Links between policy and basin hydrology for water allocation are now being used to allocate water among users based on flow and shortage rights, consumptive rights and irrigation efficiencies (Green and Hamilton, 2000), although the recent implementation of new approaches needs to be better assessed

**A territorial approach to the examination of land management has mitigated issues of land insecurity, inequitable distribution of land, and social conflict.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| S | C | -4 to +3 | G | Wide applicability |

Customary land tenure issues can potentially create social tension, if the rights of all farmers and herdsmen are not addressed, when developing new land use practices. Understanding local land management makes it possible to assess the impact of policies and to question their relevancy (Platteau, 1996; Ensminger, 1997; DeSoto, 2005), and assess the suitability of individual land rights (LeRoy et al., 1996). Local rights and institutions are now recognized by the international authorities (Deininger and Binswanger, 2001; World Bank, 2003) and entitlement policy is no longer considered to be the only solution. Beyond the identification of the various regulation authorities (Schlager and Ostrom, 1992), the territorial approach now articulates the local level with national and international levels (Lavigne Delville, 1998; Mathieu et al., 2000), thereby taking into account the plurality of systems, local authorities and land rights.

**Research has paid little attention to the serious impacts of social conflicts and disorders on agricultural production.**

| GOALS | CERTAINTY | RANGE OF IMPACTS | SCALE | SPECIFICITY |
|---|---|---|---|---|
| N, S | D | -5 to 0 | G | Wide applicability |

Wars may arise from conflicts for agricultural resources (Collier, 2003), notably for land (Chauveau, 2003), or claims on forest (Richards, 1996), resulting in agricultural stagnation (Geffray, 1990; Lacoste, 2004); declining productivity of crops and livestock and the decreasing access and availability of food (Dreze and Sen, 1990; Stewart, 1993; Macrae and Zwi, 1994 ); destruction of storage and transformation infrastructures; ground and water pollution, higher food prices and obstacles to the transport of agricultural inputs and products. This stagnation is reinforced by factors like civil disorders, state collapse, urbanization, declining involvement of youth in agriculture, HIV and other diseases, the decline of the agricultural workforce and the development of illegal activities. Although difficult to quantify, the agricultural losses related to wars have been increasing since the 1990's (FAO, 2000a).

Post conflict programs may alleviate difficulties. This is particularly the case with the reorganization of input delivery system, as seen with the example of the Rwanda War, which was addressed by the "Seeds of Hope Project" (Mugungu et al., 1996; www.new-agri.co.uk/01-2/focuson/focuson3.html).

### 3.3 Objectivity of this Analysis

To determine the balance of this assessment in terms of reporting on positive and negative impacts of AKST, the frequency distribution of reported impacts was determined for each main part of the Chapter (Figure 3.8). The result indicates that about one-third of reported impacts were negative and two thirds positive. Although there were small differences between the subchapters, the trends were similar, suggesting that the authors are in general agreement about balance of this Assessment and the overall outcomes of 50 years of AKST.

**[Insert Figure 3.8]**

### 3.4 Lessons and Challenges

The fundamental challenge for AKST in rural development is how to make agriculture both more productive and more sustainable as a source of income, food and other products and services for the benefit of all people worldwide, most of whom are living below or a little above the US $2 per day poverty line – but who also suffer many health, livelihood and environmental deprivations that are not best measured in dollars. A new approach to sustainable agriculture has to be achieved despite the growing population pressure on limited sources of all forms of natural capital (especially land, water, nutrients, stocks of living organisms and global climatic stability), many of which have already been severely degraded by former approaches to agricultural production, and which have externalized the costs of the environmental and social impacts of AKST. This Chapter has shown that the current serious situation has resulted from a culture of exploitation, coupled with a uni-dimensional approach that failed to appreciate and develop the multifunctionality of agriculture.

The overriding lesson of this chapter is that although AKST has made great improvements in productivity the global focus of AKST to date on production issues has been at the expense of environmental and social sustainability at the local level. Consequently, natural resources have typically been overexploited and the societies have lost some of their traditions and individuality. The sustainable implementation of AKST has been impeded by inadequate understanding, inappropriate policy interventions, socioeconomic exclusion, and a failure to address the real needs of poor people. This has been exacerbated by an over-emphasis on trade with industrialized countries and a set of ‘disconnects’ between disciplines, organizations and different levels of society that have marginalized environmental and social objectives. In developing countries, and especially in Africa, the combined effect has been that poor people’s livelihoods have not benefited adequately from the Green Revolution and from globalization, due to their exclusion from the benefits of AKST. At the same time, there is a diverse body of work on improving the productivity of degraded farming systems that is based on more sustainable approaches. These are more socially-relevant, pro-poor, approaches to agriculture, with a strong reliance on both natural resources and social capital at community and landscape levels. This body of evidence, albeit disparate at present, is largely based on diversified and integrated farming systems, which are especially appropriate for the improvement of small-scale farms in the tropics. It has a stronger emphasis on environmentally and socially sustainable agriculture and offers the hope of a better future for many millions of poor and marginalized rural households. The overriding challenge is, therefore, to revitalize farming processes and rehabilitate natural capital, based on an expanded understanding of INRM within AKST. Much of this will involve the provision of appropriate information for policy-makers and farmers and the removal of the ‘disconnections’ between different disciplines, organizations and levels of society at the heart of AKST. This will be fundamental for the integration of the different components of AKST and the scaling-up of the existing socially and environmentally sustainable agricultural practices.

This Chapter has presented an analysis of the positive and negative impacts of AKST over the last 50 years, which allows us to address the key IAASTD question: “*What are the development and sustainability challenges that can be addressed through AKST?*” We highlight ten concerns that pose the key AKST challenges to improving agriculture’s sustainability, while meeting the needs of a growing population dependent on a limited and diminishing resource base:

*First, the fundamental failure of the economic development policies of recent generations has been reliance on the draw-down of natural capital*, rather than on production from the 'interest' derived from that capital and on the management of this capital. Hence there is now the urgent *challenge* of developing and using AKST to reverse the misuse and ensure the judicious use and renewal of water bodies, soils, biodiversity, ecosystem services, fossil fuels and atmospheric quality.

*Second, AKST research and development has failed to address the 'yield gap'* between the biological potential of Green Revolution crops and what the poor farmers in developing countries typically manage to produce in the field. The *challenge* is to find ways to close this yield gap by overcoming the constraints to innovation and improving farming systems in ways that are appropriate to the environmental, economic, social and cultural situations of resource-poor small-scale farmers. An additional requirement is for farm products to be fairly and appropriately priced so that farmers can spend money on the necessary inputs.

*Third, modern public-funded AKST research and development has largely ignored traditional production systems for 'wild' resources*. It has failed to recognize that a large part of the livelihoods of poor small-scale farmers typically comes from indigenous plants (trees, vegetables/pulses and root crops) and animals. The *challenge* now is to acknowledge and promote the diversification of production systems through the domestication, cultivation, or integrated management of a much wider set of locally-important species for the development of a wide range of marketable natural products which can generate income for the rural and urban resource poor in the tropics – as well as provide ecosystem services such as soil/water conservation and shelter. Those food crops, which will be grown in the shade of tree crops, will need to have been bred for productivity under shade.

*Fourth, AKST research and development has failed to fully address the needs of poor people*, not just for calories, but for the wide range of goods and services that confer health, basic material for a good life, security, community wellbeing and freedom of choice and action. Partly as a consequence, social institutions that had sustained a broader-based agriculture at the community level have broken down and social sustainability has been lost. The *challenge* now is to meet the needs of poor and disadvantaged people – both as producers and consumers, and to re-energize some of the traditional institutions, norms and values of local society that can help to achieve this.

*Fifth, malnutrition and poor human health are still widespread*, despite the advances in AKST. Research on the few globally-important staple foods, especially cereals, has been at the expense of meeting the needs for micronutrients, which were rich in the wider range of foods eaten traditionally by most people. Now, wealthier consumers are also facing problems of poor diet, as urban people are choosing to eat highly processed foods that are high in calories and fat, while low in micronutrients. In addition, there are increasing concerns about food safety. The *challenge* is to enhance the nutritional quality of both raw foods produced by poor small-scale farmers, and the processed foods bought by urban rich from supermarkets. A large untapped resource of highly nutritious and health-promoting foods, produced by undomesticated and underutilized species around the world, could help to meet both these needs. Negative health impacts have also arisen from land clearance, food processing and storage, urbanization, use of pesticides, etc., creating procurement and marketing challenges for food industries and regulatory challenges for environmental and food safety organizations.

*Sixth, intensive farming is frequently promoted and managed unsustainably resulting in the destruction of environmental assets and posing risks to human health, especially in tropical and sub-tropical climates*. Many practices involve land clearance, soil erosion, pollution of waterways, inefficient use of water, and are dependent on fossil fuels for the manufacture and use of agrochemicals and machinery. The key *challenge* is to reverse this by the promotion and application of more sustainable land use management. Given climate change threats in particular, we need to produce agricultural products in ways that both mitigate and adapt to climate change, that are closer to carbon-neutral, and that minimize trace gas emissions and natural capital degradation.

*Seventh, agricultural governance and AKST institutions alike have focused on producing individual agricultural commodities*. They routinely separate out the different production systems that comprise agriculture, such as cereals, forestry, fisheries, livestock, etc, rather than seeking synergies and optimum use of limited resources through technologies promoting Integrated Natural Resources Management. Typically, these integrating technologies have been treated as fringe initiatives. The *challenge* now is to mainstream them so that the existing set of technologies can yield greater benefits by being brought together in integrated systems. A range of biological, ecological, landscape/land use planning and sustainable development frameworks and tools can help; but these will be more effective if informed by traditional institutions at local and territorial levels. Because of the great diversity of relevant disciplines, socioeconomic strata and production/development strategies, sustainable agriculture is going to be more knowledge-intensive than ever before. This growing need for knowledge is currently associated with a decline in formal agricultural extension focused on progressive farmers and its replacement by a range of other actors who often engage in participatory activities with a wider range of farmers, but who often need greater access to knowledge. Thus part of the challenge is to reinvent education and training institutions (colleges, universities, technical schools and producer organizations), and support the good work of many NGOs by also increasing long-term investments in the upstream and downstream transfer of appropriate knowledge.

*Eighth, agriculture has also been very isolated from non-agricultural production-oriented activities in the rural landscape*. There are numerous organizational and conceptual 'disconnects' between agriculture and the sectors dealing with (i) food processing, (ii) fibre processing, (iii) environmental services, and (iv) trade and marketing and which therefore limit the linkages of agriculture with other drivers of development and sustainability. The *challenge* for the future is for agriculture to increasingly develop partnerships and institutional reforms to overcome these 'disconnects'. To achieve this it will be necessary for future agriculturalists to be better trained in 'systems thinking' and entrepreneurship across ecological, business and socioeconomic disciplines.

*Ninth, AKST has suffered from poor linkages among its key stakeholders and actors.* For example: (i) public agricultural research is usually organizationally and philosophically isolated from forestry/fisheries/environment research; (ii) agricultural stakeholders (and KST stakeholders in general) are not effectively involved in policy processes for improved health, social welfare and national development, such as Poverty Reduction Strategies; (iii) poor people do not have power to influence the development of prevailing AKST or to access and use new AKST; (iv) weak education programs limit AKST generation and uptake (especially for women, other disadvantaged groups in society and formal and informal organizations for poor/small farmers) and their systems of innovation are not well connected to formal AKST; (v) agricultural research increasingly involves the private sector, but the focus of such research is seldom on the needs of the poor or in public goods, (vi) public research institutions have few links to powerful planning/finance authorities, and (vii) research, extension and development organizations have been dominated by professionals lacking the skills base to adequately support the integration of agricultural, social and environmental activities that ensure the multifunctionality of agriculture, especially at the local level. The main *challenge* facing AKST is to recognize all the livelihood assets (human, financial, social, cultural, physical, natural, informational) available to a household and/or community that are crucial to the multifunctionality of agriculture, and to build systems and capabilities to adopt an appropriately integrated approach, bringing this to very large numbers of less educated people – and thus overcoming this and other 'disconnects' mentioned earlier.

*Finally, since the mid-20th Century, there have been two relatively independent pathways to agricultural development – the 'Globalization' pathway and the 'Localization' pathway.* The 'Globalization' pathway has dominated agricultural research and development, as well as international trade, at the expense of the Localization; the grassroots pathway relevant to local communities (Table 3.5). As with any form of globalization, those who are better connected (developed countries and richer farmers) tend to benefit most. The *challenge* now is to redress the balance between Globalization and Localization, so that both pathways can jointly play their optimal role. This concept, described as Third-Generation Agriculture (Buckwell and Armstrong-Brown, 2004), combines the technological efficiency of second-generation agriculture with the lower environmental impacts of first-generation agriculture. This will involve scaling up the more durable and sustainable aspects of the community-oriented 'grassroots' pathway on the one hand and thereby to facilitate local initiatives through an appropriate global framework on the other hand. In this way, AKST may help to forge and develop Localization models in parallel with Globalization. This approach should increase benefit flows to poor countries, and to marginalized people everywhere. This scaling up of all the many small and often rather specific positive impacts of local AKST held by farmers and traders could help to rebuild natural and social capital in the poorest countries, so fulfilling the African Proverb:

*"If many little people, in many little places, do many little things, they will change the face of the world."*

**[Insert Table 3.5]**

This will also require that developed country economies and multinational companies work to address the environmental and social externalities of the globalized model ('Enlightened Globalization'), by increasing investment in the poorest countries, by honoring their political commitments, and by addressing structural causes of poverty and environmental damage with locally available resources (skills, knowledge, leadership, etc). In turn, this is highly likely to require major policy reform on such issues as trade, business development, and intellectual property rights – especially in relation to the needs of poor people, notably women.

The ten lessons above have drawn very broadly on the literature. A specific lesson-learning exercise covering 286 resource-conserving agricultural interventions in 57 poor countries (Pretty et al., 2006) offers an illustration of the potential of implementing more sustainable approaches to agriculture with existing strategies and technologies. In a study covering 3% of the cultivated land in developing countries (37 million ha), increased productivity occurred on 12.6 million farms, with an average increase in crop yield of 79%. Under these interventions, all crops showed gains in water use efficiency, especially in rainfed crops and 77% of projects with pesticide data showed a 71% decline in pesticide use. Carbon sequestration amounted to 0.35 tonnes C $ha^{-1}y^{-1}$. There are grounds for cautious optimism for meeting future food needs with poor farm households benefiting the most from the adoption of resource-conserving interventions (Pretty et al., 2006). Thus great strides forwards can be made by the wider adoption and up-scaling of existing pro-poor technologies for sustainable development, in parallel with the development of ways to improve the productivity of these resource-conserving interventions (Leakey et al., 2005a). These can be greatly enhanced by further modification and promotion of some of the socially and environmentally appropriate AKST described in this chapter.