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CHAPTER 3

IMPACTS OF AKST ON DEVELOPMENT AND SUSTAINABILITY GOALS

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Key Messages

1. Advances in AKST have enabled substantial gains in agricultural production, which have reduced levels of hunger.

- World cereal production has more than doubled since 1961, with average yields per hectare increasing around 150% in many high- and low-income countries, with the notable exception of most nations in sub-Saharan Africa.
- Increased cereal yields and hence calorie consumption have resulted in lower levels of hunger; e.g. chronic hunger in Asia has halved from 40% to 20% and had consequent benefits to people's nutrition and health. However, unacceptable levels of hunger remain as a global problem. Improved cereal yields have contributed to better farmers' livelihoods and economic growth in some countries.
- In developing countries the proportion of people consuming less than 2200 kcal per day dropped from 57% in 1964-66 to 10% in 1997-99.
- Hunger and malnutrition have not been eliminated by the above gains.
- A recent expansion of AKST to vegetables, pulses and fruits has diversified diets and led to some lowering of micronutrient deficiencies.
- Recent developments in biotechnology, and especially the development of new transgenic cultivars, may offer opportunities for a new generation of technological KST. Currently, a few multinational companies favour this new technology. However, adoption of transgenic technologies by farmers has only occurred in 22 countries (50:50 developed and developing) where governments have endorsed the technology and regulatory systems are in place to assess concerns about the ecological, social and health impacts.

2. Despite much progress in crop and livestock breeding and in agricultural technologies, persistent problems remain: (i) uneven capacity to make use of AKST, and (ii) uneven distribution of benefits from AKST. As a consequence human health continues to decline and environmental degradation is widespread. Although agriculture is potentially a major vehicle for poverty reduction, poverty still affects about 3.2 billion people (with incomes under US$2 per day).

• *Uneven capacity to make use of AKST*

- Regions, countries and social groups differ in their access to resources, commercial and other infrastructure, and agricultural services and inputs. In addition, policy instruments and commercial pressures (e.g. trade rules and regulations and property rights) have often made AKST irrelevant or inaccessible – especially in relation to the needs of poor people and especially women.

• *Unevenly distributed benefits.*

- Poor countries in sub-Saharan Africa have gained proportionately less from increased productivity than some richer countries (USA, Europe, Asia and Latin America), with Industrialized countries gaining the most in absolute terms.
- Major benefits from increased productivity have not occurred in marginal agro-ecological regions, especially rain-fed dryland areas, and have eluded marginalized people (poor

farmers, landless people, shifting cultivators, seasonally mobile populations and women), with an estimated 800 million persons still food insecure. The reasons vary and are complex.

- In industrial agriculture, characterized by: relatively large scale, high input levels, high capitalization and institutional support networks, research, extension, subsidization of inputs, protection, etc., has typically led to the business making more turnover/net profit per worker.
- In smallholder agriculture, characterized by: small-scale, low input levels, little or no capital, and minimal institutional support, especially in marginalized areas, poor farmers cannot compete in the world markets, especially in regulated international trade, and indeed often lack adequate investment income to even participate effectively in local and regional markets. Poor farmers are highly vulnerable in crisis situations and to changing climate, as well as being unable to contribute to national food security and food sovereignty.

• *Negative health impacts have arisen from dietary changes, use of pesticides, land clearance, etc.*

- Despite the increase in global food production, malnutrition is still a major problem. There are 800 million underweight and undernourished people. Conversely, greater disposable incomes and changes in lifestyle have resulted in an increase, mainly by urban dwellers, in the consumption of highly processed foods that are high in calories, fat and sugar, and low in micronutrients. Consequently, worldwide there are 1.6 billion overweight adults, with 400 million adults suffering from obesity, with its related problems of diabetes and heart disease. The combination of these two forms of malnutrition means that many less developed countries are now suffering from the double burden of diet-related disease due to both micronutrient deficiencies and obesity.
- Inadequate coordination between systems of human health, agriculture knowledge and public decision making systems has undermined the potential of each to control major diseases.
- Misuse of agrichemicals and environmental contamination harm human health, which in turn can affect agricultural production through reduced labour productivity.

• *Agricultural exploitation of natural capital has resulted in substantial environmental degradation of land, waterways, oceans and the atmosphere.*

- Land degradation adversely affects the ecological integrity and productivity of landscapes used by 2.6 billion people, and consequently has a direct impact on human livelihoods.
- Agricultural demands on land and water have often degraded natural resources (soils, biodiversity, freshwater, carbon-derived energy) and environmental services (nutrient and water cycling, microclimate, food chains and life cycles, pest and disease control, pollination, etc) in increasingly large areas, because overexploitation has breached the ecological thresholds beyond which natural processes collapse.
- Additionally, problems arising from intensive usage of external inputs (pesticides/fertilizer/irrigation water, etc.) are on the increase, especially in countries

experiencing rapid economic growth. These include the accumulation of agricultural contaminants in watercourses including fisheries, drying up of wetlands and freshwater bodies.

- The depletion of soil fertility results in a yield gap between the biological potential of a crop and the yield actually achieved by farmers. This is especially important in poor countries where farmers may not be able to afford the fertilizer amendments required to close this gap.
- The growing reliance on fossil fuels has increased emissions of ‘greenhouse gases’ – notably CO_2, CH_4 and NO/N_2O, contributing to global and local climate change.
- This environmental degradation feeds back negatively to agriculture itself – eroding the natural foundations upon which it depends.

3. Agriculture has multiple functions (food production from crops, livestock, fish; production of a wide range of non-food products; post-harvest processing; natural resource and environmental protection; advancement of livelihoods; trade and marketing; food safety; maintenance of culture, tradition and identity, etc). Through multi-functional agriculture degraded land can be rehabilitated, and because individual functions share common resources, total productivity is less land and resource intensive than mono-cropping. Thus sustainable agriculture requires an integrative and iterative approach that can handle the associated complexities.

The successful development of sustainable practices will not be achieved by focusing on individual components of AKST in isolation. Single crops, animal products and technologies alone rarely offer the public environmental benefits of multi-functional agriculture that are increasingly in demand. Over the last 15 years, a range of multifunctional KST initiatives, involving an Integrated Natural Resources Management (INRM) approach to agricultural diversification, have been shown to simultaneously meet the livelihood needs of the poor and tackle problems of unproductive and degraded local environments, by proactively promoting the pursuit of environmental and social goals in addition to improved total productivity and income.

- Innovative integrated agricultural systems producing ecosystem goods and services - Integrated Pest Management, Integrated Nutrient Management, Integrated Water Management, agroforestry, ecoagriculture - have emerged, enabling agriculture to work ‘with’ nature, rather than ‘against’ it. Some of these multi-goal initiatives have emphasized participatory engagement of stakeholder groups: local communities and farmers, civil society organizations, interdisciplinary science and environmental groups.
- INRM initiatives have also involved: advocacy for local food systems and farmers’ rights, market mechanisms that reward multi-functional production; integrated landscape/ territorial/ land use planning approaches; sustainable development strategies and certification of organic/ fair trade/ sustainability status. When and where integration is impossible, such methodologies aim at optimizing trade-offs, although policy and market conditions often limit the ability to make the best decisions. Unlike the globally driven

initiatives of the past, these locally-driven integrated land use systems have resulted in AKST advances that promote sustainable rural development.

- INRM technologies and approaches typically include community-based innovations that draw on traditional knowledge and use participatory approaches for community engagement. A promising example is the domestication and cultivation of indigenous fruit and nut trees to produce non-wood products previously gathered from forests. In parallel with domestication, marketing initiatives are essential to develop processing, value addition and trade. Local tree species are commonly used to diversify farming systems, produce marketable and highly nutritious foods (fruits, nuts, oils), pharmaceutical/nutriceutical/cosmetic products, and timber/fibre/resins for construction and energy. These trees also provide environmental services, such as soil fertility restoration, carbon sequestration and improved agroecosystem function. The successful application of INRM approaches can help to close the gap between potential and actual crop yields thereby increasing the returns from investment in the Green Revolution.
- INRM innovations are typically based on local culture, and support this while promoting gender equity. They are associated with reduced vulnerability to crop failures by improving soil fertility, and supporting hydrological and biological processes on farms. Some of the indigenous tree crop innovations are beginning to attract the interest of multi-national companies, as there is high potential for new crops to make substantial gains in partnership with local communities, in contrast to some existing crops.
- Current private sector interest includes crop diversification to promote lower dependence on fossil fuel for energy production and to mitigate climate change. This involves the use of agricultural crops, biomass residues, ‘biofuel’ crops for bioenergy.

4. Sustainable agriculture is more knowledge- intensive than ever before, covering social, ecological and economic dimensions that, in changing circumstances, require stakeholders to be better informed.

Multiple goals require flexible and responsive innovation systems based on sound AKST. Given the increasing limitations on land availability, plus the continued evolution of pests, diseases, markets and environmental change, AKST has to keep evolving for agriculture to even ‘stand still’. Successful AKST involves keeping abreast of these highly diverse and dynamic conditions and their consequences for sustainable living. All stakeholders (from the farmers to international policy makers) therefore require access to a range of different types of knowledge and information:-

- Indigenous and local technical knowledge – particularly in mixed cropping and the use of indigenous plants and animals for food and health benefits.
- Indigenous and local socio-cultural knowledge – culture, systems of organization and belief systems regarding resource use and management, such as community-based soil and water management
- Biological and genetic knowledge – including scientific and indigenous approaches to selection and breeding, coupled with information at the molecular and gene level

- Environmental knowledge and technology – especially concerning agriculture's dependence and impacts upon natural resources, local ecosystems, climate change and variability, and trade-offs between production and other ecosystem services
- Post-harvest processing knowledge – to support value addition, marketing and efficiency gains
- Knowledge about consumers – of both demands for food, and new demands beyond food (environmental services, energy production, bio-pharmaceutical production, etc)
- Market chain knowledge – notably of demands for food quality and safety (although this is rapidly restructuring the food market, farmers do not always have access to appropriate AKST),
- Knowledge about information technology and innovation – to transform agriculture into economically viable development opportunities.

As yet, few formal information systems effectively integrate this wide range of knowledge and make it accessible to end-users. In contrast, at local levels, informal knowledge systems have shown remarkable resilience, adaptation and innovation in responding to change and achieving synergies. However, poor linkages with formal AKST systems impose limits to how local knowledge is effectively and responsibly integrated into global knowledge and, in turn, how well local knowledge systems can deal with global change. Both publicly funded extension and emerging private sector providers are still limited in their understanding and use of local/traditional knowledge or ecological principles.

5. Effective AKST increasingly involves organizational partnerships and institutional reform. There is a need to realize synergies between different forms of agriculture; between agriculture and other sectors; between different disciplines; and between local and global institutions.

- Within agriculture – linkages between farming, forestry and fisheries are frequently rich in local/indigenous organizations. Formal institutions have traditionally been separate, but more recently have improved the linkages by focusing on livelihoods, landscapes, and/or natural capital. KSTs in remote sensing, mapping, resource assessment and valuation, and land use planning have potential, but continued institutional separation still limits their utility.
- Between agriculture and other sectors – linkages with the non-farm sectors that are principal drivers of the IAASTD goals (notably health, infrastructure, urbanization, development and environment) are key but there is limited KST of joint utility
- Between different disciplines and knowledge traditions – linkages between natural and social sciences have proven valuable for handling specificity and difference in spatial, stakeholder, and value chain issues. However, interdisciplinary partnerships face many constraints relating to professional and organizational cultures, funding arrangements, capacity and agricultural policy.
- Between global, national and local organizations – AKST linkages have tended to be ineffective when they enable only a one-way flow from 'top down'; but are more effective when they have engaged farmers and vulnerable groups in scaling up locally-specific AKST

and/or increasing access to that 'universal' AKST which they believe best meets their needs.

6. Since the mid 20th Century, there have been two relatively independent pathways to agricultural development: Globalization and Localization. Effective AKST is beginning to bring these pathways together. 'Globalization', which has dominated formal AKST, has been initiated in developed countries and has been driven by public-sector agricultural research, international trade and marketing and international policy. 'Localization' has come from the grassroots of civil society and has involved locally based innovations meeting the everyday needs of local people and communities. To date, this second pathway has been overshadowed by Globalization. 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 notably through successful public/private partnerships (e.g. fair-trade tea/coffee, forestry outgrowers) involving global companies and local communities, offering new paradigms for economic growth and development, that mobilize and scale-up locally appropriate AKST in ways that integrate agricultural production with economic, social and environmental sustainability

3.1 Background and Methodology

The Goals of this International Assessment of Agricultural Science and Technology for Development reflect an evolution of the concept of Agriculture from a strong technology-oriented approach at the start of the Green Revolution to a much more people- and environment-oriented approach today. Assessing the biophysical impacts of AKST is simpler than assessing the social impacts, because the former are less complex and there has been a longer period of research, although most of this has been on-station, rather than on-farm. This evolution of agriculture is evident in the expansion of the CGIAR to include Centers with a strong focus on natural resources management, and the recent shift to a greater focus in all Centers, and some independent organizations, 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.

Chapter 1 has presented the context, conceptual framework of the Assessment and the sustainability indicators used, while Chapter 2 presents a historical analysis of the effectiveness of AKST systems in promoting innovation. The latter includes an examination of science, knowledge, technology and innovation systems; the actors, institutional arrangements and drivers of change; and the evolution of AKST. In this Chapter we assess the impacts of AKST on rural development worldwide over the last 50-60 years, with particular regard to the impacts on the economic, social and environmental sustainability of rural development from the farm level to the global level.

The preparation of this Chapter started with a review of the international literature, in learned journals, conference proceedings, the reports of many and various organizations from international and non-governmental 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 the IAASTD ‘Goals’ and ‘Questions’ (see Chapter 1).

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

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

Finally, levels of certainty were attributed to impact and sustainability statements. These statements were based on evidence found in the international literature and the personal experience of the authors. This certainty was then associated with the range of impacts reported and to measures of scale and specificity (Table 3.1).

[Table 3.1]

3.2 Assessment and Analysis

3.2.1 Impacts of AKST on productivity, consumption and basic production factors

3.2.1.1 Food production, consumption, and human welfare

Modern agricultural science and technology has positively impacted a high proportion of people worldwide.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 6	A	0 to +3	G	Especially in industrial and transitional countries

From 1970 to 2003, the human population has nearly doubled in many regions, with an 82% increase in the Asia/Pacific region and 91% in Latin America/Caribbean, while populations in sub-Saharan Africa (SSA) have increased 149% (FAOSTATS, 2007). Despite these increases in population, agricultural systems have provided sufficient food resources to reduce undernourishment rates by about 50% in Asia/Pacific and Latin American/Caribbean since 1970 (Figure 3.1). In contrast, rates of undernourishment in sub-Saharan Africa (SSA) have only marginally improved since 1970 with approximately 216 million undernourished people in 2003 (FAO Statistics Division, 200?). Within SSA, however, there are remarkable differences among regions: undernourishment rates in Central Africa have nearly doubled to 57%, whereas strong progress has been made in West Africa with rates dropping from 31 to 15% of the population from 1970 to 2003.

[Figure 3.1]

AKST, especially public-funded agricultural science research, has made substantial contributions to the reduction of malnourishment (Tribe, 1991).

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 6	A	0 to +3	G	Especially in industrial and transitional countries

Large increases in agricultural production of vegetables, roots and tubers, cereals and latterly pulses (Figure 3.2), have been made possible by the extensive use of genetic improvement, soil fertility management, irrigation, pesticides and mechanization (FAO 2002b). Some 1.2 billion people, mostly in developed countries, are supported by agricultural systems relying heavily on external inputs, while 2.3-2.6 billion people are supported by Green Revolution technologies (Pretty, 1995)

Nonetheless, some estimates suggest that 28-34% of the world's population has not been impacted by modern agricultural science. On a global scale, AKST has increased the production of calories, fats/oils, proteins and micronutrients per head (FAO 2002; Evenson and Gollin, 2003ab). For example, the proportion of people living in developing countries consuming <2200 kcal per day has fallen from 57% in 1964-66 to 10% in 1997-99 (FAO, 2002). Prices for staple foods have also declined (McCalla, 1998), benefiting the poor since they spend a large portion of their income on food. However, AKST benefits have been unevenly realized among and within regions and, when realized, often accompanied by significant detriment to the environment and to human health (Cassman et al., 2005).

[Figure 3.2]

Agricultural science and technology has had positive impacts on the productivity (yield per unit area) of staple food crops, but impacts have been distributed unevenly.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,6	A	+1 to +5	G	Especially in industrial and transitional countries

Either from direct consumption or indirectly as feedstock, the cereal staples maize, rice, and wheat contribute around 60% of the caloric energy for humans on the global scale. Among industrialized countries, the developing regions of Asia and in LAC, average cereal yields (Mg ha^{1}) have sustained impressive annual rates of increase (43 to 62 kg ha^{1} yr^{-1}), and have more than doubled in absolute terms since the 1960s (Figure 3.3). In contrast, the average cereal yields among developing countries in Africa has increased at a rate of 10 kg ha^{-1} yr^{-1} and, at present, have productivity levels of around half of those in industrialized countries in 1961. These broader trends mask significant differences among the grain staples. In developed countries, maize productivity has grown at average rate of 122 kg ha^{-1} yr^{-1}, increasing from a base of 3 Mg ha^{-1} in 1961 to nearly 8 Mg ha^{-1} in 2005. In 1961, maize productivity was approximately 1 Mg 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 programmes (Table 3.2). Similar trends are evident in rice productivity with average rates of increase of 57 (Asian developing countries), 43 (Central America) and 13 (Africa) kg ha^{-1} yr^{-1}. Rates of yield advance are not as divergent for wheat, with developing regions in Africa experiencing approximately 50% of those achieved in Central America and developing regions of Asia. Similar trends are apparent for other major commodities such as vegetables and roots and tubers (Figure 3.3). While average pulse productivity has doubled in industrialized countries, yields have not susbstantially increased in Africa, Asia, and Latin America (Figure 3.3).

[Table 3.2] and [Figure 3.3]

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,3,4, 6	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 as predicted by simulation models (Cassman et al., 2003). Cassman et al. (2003) and Pingali and Heisey (1999) suggest that this type of stalled exploitation of potential production is primarily caused by economic factors: the rigorous management practices required for yield maximization are not cost effective. 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, analysis in the 1990s suggested that rice yield potential was actually declining 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., 2002). 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 (Duvek and Cassman, 1999). For spring wheat producers in Mexico's Yaqui Valley, only nominal increases in yield have been observed since the late 1970s (Figure 3.4).

[Figure 3.4]

Recently horticulture has been the fastest growing food sector worldwide

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,6	B	+1 to +3	G	Especially China

Horticulture production has increased from 495 mt in 1970 to 1379 mt in 2004 (178%). In comparison, cereal, livestock, and fish production was less than or equal to 100% (Ali, 2006). The vegetable sub-sector has grown at an annual average rate of 3.6% during 1970-2004, from 255 mt in 1970 to 876 mt in 2004 (Ali, 2006). Most of this increased production came from an expansion of the area under horticulture. The annual increase in per ha yield increased at less than 1% in 1970-2004. The slow improvement in the yield of horticulture crops suggests the neglect of horticultural research in the public sector. 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 impact on the 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 consumption of livestock products has been growing dramatically over the last few decades.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

1, 2, 3	A	0 to +3	G	Wide applicability

Per capita consumption of livestock products has increased quite sharply as incomes have risen (FAO, 2006a,b). For example, between 1962 and 2003, *per capita* consumption of meat grew by a factor of 2.9, and milk by a factor of 1.7 in developing countries (FAO, 2006). Among these developing countries, China, Brazil and India accounted for over 50% of meat and milk production in 2005.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,2,3,5,6	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, 2002). 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. While export-oriented, industrial and commercial aquaculture practices bring much needed foreign exchange, revenue and employment to a country, 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, 2002). The potential of aquaculture has not yet been fully realized in all countries.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2	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 6.3kg in 1970 to 13.8kg in 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 increased fish consumption in developing countries, particularly in Asia (Dey et al., 2005).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2	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 mt to nearly 130 million mt. Developing countries supply 75%of the volume - and 50% of the value - of the global fish trade. Together, the developing countries of Asia form the largest fish producer, with production reaching 71.2 million tons in 2001, representing 55% of world production (FAOSTAT, 2005). In 2001, the top ten fish producing (both capture and aquaculture) nations in terms of volume were China, Peru, India, Japan, the USA, Indonesia, Chile, the Russian Federation, Thailand and Norway. Asia is the leading contributor to this expansion, accounting for over 63% of total fish production and as much as 90% of all aquaculture output (FAO, 2004; 2005). Aquaculture currently represents about 32% of total fisheries production mostly coming from developing countries, especially Asia, and accounts for an increasing share of global trade, and provides approximately 40% of the world's total food fish supply (Delgado et al., 2003ab). 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, fertilizer, pesticides, and mechanization)

Most of the increases in agricultural production (crops, livestock, aquaculture) since the 1960s are linked to higher rates of productivity per unit area rather than area expansion, but there are significant regional differences.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,2,3,6	B	-1 to +3	G	

For many commodities (e.g. cereals), world agricultural production has more than doubled since the 1960s. Growth in aggregate production can be achieved by increasing productivity, expanding the area in production, or by increasing production intensity with strategies such as cultivation during periods that were previously fallow. On a global scale, Bruinsma (2003) estimates that 71% of the increase in crop production since 1961 can be attributed to increases in productivity with the remainder due to area expansion. However, these proportions are reversed in the case of sub-Saharan Africa with approximately 66% of the crop production increase since 1961 linked to area expansion.

Land reserves for future expansion of agricultural production are limited on a global scale

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,4,6	A	-1 to +2	G	

Cultivated systems occupy approximately 24% of the earth's land surface with most of world's prime land for agriculture already in cultivation (Cassman et al., 2005). 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 would limit profitable and sustainable production (Wood et al., 2000). Moreover, many of the remaining undeveloped areas are of regional and global importance for the biodiversity and ecosystem services they provide (Bruinsma, 2003). To conserve natural areas and to avoid production on sensitive land units (e.g. highly erodible land), there are strong imperatives for continuing the growth of agricultural production through intensification rather than area expansion.

Globally there has been extensive increase in the area irrigated.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,4	B	-1 to +5	G	Especially Asia

Globally, irrigation had been applied to 267 million ha by 2000 (Huber-Lee and Kemp-Benedict, 2003 quoted by Jinendradasa, 2003), but proportionally sub-Saharan Africa has benefited the least from this expansion. Half of the world's irrigated land is in Asia (Brown, 2005), with some 80% of China's grain harvest coming from irrigated land. In India, over half of the grain harvest comes from irrigated land, while in USA, irrigated land accounts for 20% of the grain harvest (Brown, 2005). However, 15-35% of global irrigation supply is estimated to be unsustainable as the rate of groundwater withdrawal exceeds recharge.

Increased fertilizer use is closely linked to crop productivity gains in regions that have been most successful at reducing undernourishment.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,2,3,4,6	A	+2 to +5	G	Especially in Asia

On a global scale, total fertilizer consumption has increased from approximately 31 million mt in 1961 to 142 million mt in 2002 (FAOSTATS, 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 (FAOSTATS, 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 (Figure 3.5) remains exceptionally low at under 20 kg ha^{-1} yr^{-1} (FAOSTATS, 2006). For cereal crops, estimates suggest that approximately 50% of the yield increases observed in places like India after the introduction of HYVs can be attributed to increased fertilizer use (Bruinsma, 2003).

[Figure 3.5]

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

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

Total factor productivity, 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 (Figure 3.6). The index of Total Factor Productivity 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 Prasada 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 (Coelli et al., 2003). 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).

Figure 3.6

3.2.1.1.2 Agriculture 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
1, 2, 3, 4, 5, 6	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* BNF). In the tropical countries where shifting (swidden) agriculture is the traditional approach to regenerating soil fertility, increasing population pressure have resulted in shorter periods of fallow and often severe reductions in stocks of organic carbon and soil nutrients (Palm et al., 2005b). Nutrient depletion is particularly acute in many of the continuous cereal production systems in the Indian Sub-Continent, Southeast Asia, and sub-Saharan Africa, especially since many of the soil 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 supplying capacity (Lal, 2006; Vanlauwe and Giller, 2006). Henao and Baanante (2006) estimate that 85% of African agricultural land (ca. 185 million ha) have net depletion rates of nitrogen, phosphorous, and potassium (NPK) that exceed 30 kg ha^{-1} yr^{-1}, with 21 countries having NPK depletion rates in excess of 60 kg ha^{-1} yr^{-1} (Figure 3.7).

Figure 3.7

Productivity-enhancing technologies are often associated with negative environmental externalities, but in many cases degradation may be primarily caused by inappropriate policies and management practices, rather than from intrinsic properties of the technologies.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	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 by Maredia and Pingali (2000) concluded that empirical evidence for these associations only exists for three scenarios - salinity, lower soil fertility, and pesticides and health. Furthermore, many of 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 over-exploitation of groundwater for irrigation (Pimentel et al., 1997 cited in Maredia and Pingali) and a lack of a complementary investment in drainage to reduce salinity problems in irrigated areas with poorly-drained soils (NAS, 1989 cited in Maredia and Pingali). Maredia and Pingali (2001) also highlight the need for a counterfactual argument, i.e. what would have happened in the absence of yield enhancing technologies. 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 (Millennium Ecosystem Assessment, YEAR).

Resource-conserving technologies (RCTs) may reduce or eliminate some of the environmental costs associated with agricultural production while maintaining or enhancing crop yields

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 3, 4, 6	A, B	-2 to +5	G	Widespread

Reduced tillage systems (e.g. no-till) and, more recently, “conservative agriculture” systems (reduced tillage in combination with surface mulch and crop rotation to aid pest control) have been widely adopted by farmers in the last 25 years with some estimates suggesting 95 million hectares now under no-till management (Derpsch, 2005). The majority of this acreage is in North and South America, although major research and extension efforts are now underway in regions such as the Ingo-Gangetic Plain of South Asia (Hobbs et al., 2006). In general, no-till systems are associated with greatly reduced rates of soil erosion from wind and water, higher rates of water infiltration (Wuest et al., 2006) and groundwater recharge, and enhanced conservation of soil organic matter (West and Post, 2002). Yields may also increase with these practices, but there can be significant interactions with crop type (Halvorson and Reule, 2006), surface residue retention rates (Govaerts et al., 2005), and time since conversion from conventional tillage while the physical structure of the surface soil regenerates. Several other resource conserving technologies such as contour farming and ridging are also useful for increasing water infiltration, thereby reducing surface run-off and erosion (Habitu and Mahoo 1999; Reij et al. 1988 as cited in Cassman et al., 2005 ME).

Impacts of crop improvement on genetic diversity are not all negative.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	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 WANA, MVs occupy smaller proportions and many more TVs can be found (Evenson and Gollin 2003b).It is generally accepted that the loss of genetic diversity, due to the widespread adoption of MVs, has a negative environmental impact (Evenson and Gollin 2003ab), both reducing the availability of genes for future crop improvement, creating the possibility for inbreeding depression (with negative impacts on production), reducing a species ability to adapt to change (eg. climate change) and evolve resistance to new pest and disease outbreaks. However, this is disputed by Maredia and Pingali (2001), who suggest that evidence for this is not substantiated. Genetic diversity can vary both temporally and spatially, and both have to be taken into account in assessing impacts on diversity. Smale (1997), Smale *et al*. (1998), and Hartell *et al*. (1998) have argued that 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. This has been confirmed by a recent molecular study of genetic diversity in wheat (Reif *et al.*, 2005). Smale et al. (2002) have shown very clearly that diversity in spring wheat in developing countries measured by molecular analysis, and MV numbers, ages, areas and genealogies, has not decreased since 1965.

The causes of land degradation are complex, interactive and cyclical.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	A	-1 to -5	G	Especially severe in the tropics

Land degradation, a decline in land quality from anthropogenic factor, is initiated by overgrazing - 680 million ha, deforestation - 580 million ha, agricultural mismanagement - 550 million ha and fuelwood consumption - 137 million ha, fuelled by the desire for economic security and income across a wide spectrum of wealth classes (FAO, 1996; GEO-3, 2004). Continuous cropping, inadequate replenishment of nutrients removed in the harvested crop, and erosion lead to subsequent soil degradation (Nair et al., 1999). Other causes of agroecosystem degradation are: loss of biological diversity/soil inoculum of soil micro-organisms/exposure of soil to radiation, soil pests / diseases. In the tropics, this degradation is exacerbated by intensive monocultural practices, but with careful and prolonged management these processes are reversible. To slow, or even reverse, this cycle is difficult because of the large number of interacting biophysical and socio-economic drivers causing poverty, deforestation, overgrazing and unsustainable cropping, all of which need to be simultaneously addressed to have any real impact. Research is demonstrating that low-input farming systems involving diversification at the plot and landscape scales can address these issues at the household/community level (Cooper *et al*., 1996; Sanchez and Leakey, 1998; Leakey *et al*., 2005), but upscaling is going to be the challenge for society.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	A	-1 to -5	G	Especially in the tropics

Land degradation is a threat to food security and quality of life through its adverse effects on agronomic productivity and the environment (Eswaran, 1993; Eswaran et al., 2001, 2006). Scherr and Yadav (2001) note that Africa and Latin America probably have the highest proportion of degraded agriculture land, and Asia has the highest proportion of degraded forest. Worldwide degradation impacts 2.6 billion people in over 100 countries and covers 33% of land area in arable agriculture (reference). The following factors characterize land degradation (Guerny, 1995): erosion and loss of topsoil (70%), terrain deformation (13%), loss of nutrients (6.9%), salinization (3.9%), compaction (3.5%), pollution (1.1%), overblowing (0.6%), waterlogging (0.5%), acidification (0.3%), subsidence (0.2%). Around 73% of rangelands in drylands are currently being degraded, together with 47% of marginal rainfed croplands and a significant percentage of irrigated croplands (Gisladottir and Stocking, 2005). The total area of land affected by drought, waterlogged soils and salinity is increasing. An analysis by continent shows that Africa has the largest extent (46%) of vulnerable land and also has a proportionately greater number of persons who are affected (reference). In sub-Saharan Africa, nutrient loss is estimated between 60-100 Kg/ha/year, creating a nutrient inbalance of between -14 to -136 Kg/ha/year (Sanchez et al., 1997). Lal (1995) estimated that yield reductions due to erosion range from 2-40%, with Africa's losses estimated at 6.2%.

Global livestock production is associated with a range of environmental problems.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 4, 6	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 wildllife habitats and biodiversity (FAO, 2006b). Additionally, livestock require regular access to water resources, which they deplete and contaminate.

The mismanagement of intensive agricultural systems can impair their productive capability and degrade ecosystem quality

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,3, 6	A	-1 to -5	G	Most agricultural systems

Agroecosystem health is important for nutrient, water and carbon cycling, microclimate, pollination, pest and disease control and for the maintenance of biodiversity (Altieri, 1994; Gliessman, 1998; Collins and Qualset, 1999). Intensive production systems, such as those practiced in 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 rather more to mismanagement in unclear. Similarly, in China, grain yield would have risen 5% during 1976-89 if the rural sector had not experienced the adverse impacts of increased erosion and degradation of soil and increased salinity (Huang and Rozelle, 1995). More evidence is needed about the relationships between total factor productivity and long-term agro-ecosystem health. In some cases, intensified production on prime agricultural land may actually reduce negative impact of production on ecosystem health by reducing the incentive to extend production onto marginal lands or into natural areas (e.g. highly erodible hillslopes, http://www.ecoagriculturepartners.org/cases/CSIII.htm#2).

Competition for water supplies from non-agricultural sectors has become one of the key constraints to global food production.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5, 6	A	-1 to -5	R	Especially severe in the dry tropics

Global investment in water distribution systems for agriculture has declined relative to other sectors during the past decades. According to data from the FAO's AQUASTAT database, water withdrawal for agriculture has declined during the past 20 years. During the period of 1988-1992, agriculture water withdrawal was approximately 58% of the total withdrawal in developed countries and 76% of total withdrawal in developing countries. During the period of 1998-2002, agricultural water withdrawal decreased to 39% in developed countries and 71% in developing countries. Globally, water withdrawal for agriculture has decreased from 69 to 61% during this same period (FAOSTATS, 2006). A decline in water available for irrigation without compensating investments and improvements in water management and water use efficiency-in both irrigated and rainfed areas has been found to reduce production growth with a consequent increase in international cereal prices and negative impacts on low-income developing countries (Rosegrant and Cai, 2001).

Irrigation often causes land degradation with negative impacts on livelihoods.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	-1 to -3	R	Especially in the dry tropics

Irrigation is practiced to increase 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). In parallel with the livelihood benefits through improved production and employment, demands for irrigation water have degraded the biodiversity of wetlands (Huber-Lee and Kemp-Benedict, 2003 quoted in Jinendradasa, 2003). Reversing mismanagement of this sort requires policy interventions.

Large-scale irrigation has depleted water resources.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	A	-1 to -3	R	Especially in the dry tropics

Unsustainable use of water resources for irrigation means that extraction exceeds reharge. 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 17m, resulting in a 50% reduction in its surface area and a 75% reducton 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).

Half the world's wetlands have been drained, with 2000 freshwater fish species threatened with extinction

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

1, 2, 3, 4, 5	B	-1 to -5	G	Especially severe in the tropics

A combination of drainage for agriculture and high water consumption for agriculture and urban uses has resulted in the loss of half of the world's wetlands (about 8.6 million km^2 = 6.4% of the Earth's surface) over the last century (Shine, de Klemm, 1999, Ramachandra, 2001; IUCN, 2000, p9). Consequently, some rivers no longer reach the sea and over 2000 freshwater fish species are now either endangered or extinct (http://www.damsreport.org/wcd_overview.htm). Worldwide the number of freshwater species is estimated to be between 9,000 and 25,000 (McAllister et al, 1997 reported in Cosgrove and Rijsberman, 2000). There has also been severe eutrophication of aquatic habitats. Freshwater biological diversity is high relative to the limited portion of the earth's surface covered by freshwater. Freshwater fish make up 40% of all fish, and freshwater mollusks make up 25% of all molluscs. Available data suggests that 20–35% of freshwater fish are vulnerable or endangered, mostly because of habitat alteration. Other factors include pollution, invasive species, and over-harvesting.

Misuse of agrichemicals contributes to degradation and pollution of water resources.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	A	-1 to -5	G	Most agricultural systems

Traces of the herbicide 'Atrazine' and other potential carcinogens are routinely documented in ground and surface waters in industrialized countries (United States Geological Survey, 1999), and pollution is increasing the cost of extraction from aquifers as extraction rates exceed recharge (World Health Organization, 2005). Pollution with pesticides and nitrates is now restricting water use for agriculture and human consumption (WMO 1997; Foster and Chilton 2003). More than 60% of the nitrogen fertilizer and herbicides used in the United States are applied in the midwestern states for corn and soybean production (United States Department of Agriculture, 2001) creating a major source of contamination (Kolpin et al., 1996) as nutrients and pesticides entering waterways (Pimentel et al., 1995; Udawatta, et al., 2004). In the USA, total nitrogen concentrations have been found to be nearly nine times higher downstream of agricultural lands than downstream of forested areas, with the highest concentrations found in the corn belt of the Midwest (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). To mitigate these negative effects of conventional farming on more than 45 million ha of non-federal cropland, the United States supports agroforestry as a component of an improved land use strategy (Udawatta, et al., 2002; Pierce et al., 2001; Stamps et al., 2002).

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
2	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 actually 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 (Jimenez and Asano, 2005; 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 waste water generated in towns has further use in urban agriculture. These estimates take account of urban horticulture, aquaculture as well as livestock, and further state that 25-80% urban households engage in some form of agriculture (Raschid-Sally, 2006). In many developing countries in Asia, Africa and Latin America, use of sewage sludge is well established over a long period of time (Strauss, 2000). The risks associated with downstream recycling waste waters 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 (2006) are recognizing 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 a long time.

Logging and the increasing scale of forest plantations operations may cause significant disruption to local farming systems from fires, herbicides, water abstraction, invasive species, changing labour profiles.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	C	-3 t0 0	R	Wide applicability

This is often a result of companies being given exclusive rights to apparently 'vacant' land on which local people depended (Carrere and Lohmann, 1996; Evans and Turnbull, 2004). Local communities have often been disadvantaged by logging concessions, with employment opportunities not compensating for lost access to forest resources.

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
1, 2, 3, 5	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 73kg per person (Ali and Abedullah, 2002). Likewise, *per capita* consumption of pulses, in south Asia, fell from 17kg in 1971 to 12kg in 2003 (Ali et al 2005a). Recently, however, vegetable production has increased in developing countries, through involvement of the public-private collaboration in the introduction of modern varieties and technologies. This transition in nutrition is causing 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, 2001). While rising income is a major driver of the nutrition transition, other factors shape demand, including changes in food availability, the power of the retail sector and marketing activities. A positive trend in developing countries is that towards increased protein consumption, such as meat and dairy products, but unless produced for home consumption, these are expensive foods mainly available 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
1, 2, 3, 5	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. Loss of habitat through deforestation, population growth, increased urbanization and poverty and an emphasis on staple food cultivation, this wild resource has diminished. Partly this is due to better access to food crops and purchased foods (Arnold and Ruiz Pérez, 1998) as the global trends have been towards diet simplification, reduced fresh food supply, and disappearance of nutrient rich indigenous food with consequent negative impacts on food diversity and security, nutritional balance, and health (IPGRI-Green Flow, 2005). Indigenous fruits and vegetables have been given low priority by policy makers, although they are still an important component of diets, especially in Africa. These trends were reinforced by the fast-food trends in metropolitan areas, and the increasing tendency for women to take on employment.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	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 are promoting traditional foods as new crop plants (Leakey, 1999a; Leakey et al., 2005) and encouraging their consumption. For example in Zambia, the FAO Integrated Support to Sustainable Development and Food Security Programme (IP-Zambia) is promoting the consumption of traditional foods (www.fao.org/sd/ip).

3.2.1.2 Genetic improvement of plants

Agriculture began with the domestication of wild animals and plants. The origins of agriculture have been extensively studied (Damania et al. 1998) and agriculture is believed to have begun independently in three different areas, which were centers of diversity as a result of co-evolution of man over millennia (Harlan 1975). About 1000 plant species have been domesticated to produce a little over 100 food and 30 non-food crops (fibre, fodder, oil, latex, etc., excluding timber). Approximately 0.3% of the species in the plant kingdom have been domesticated for agricultural purposes (Simmonds, 1976), with a further 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, 1994). These proportions 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 by people being domesticated through AST

3.2.1.2.1 Conventional breeding with and without modern biotechnologies

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
1	A	+2 to+5	G	Widespread applicability

Yield per unit area of the world's staple food crops, especially the cereals rice, wheat and maize have increased over the last 50 years (Figure 3.3a), as a result of public and private-funded research on genetic selection and conventional breeding (Simmonds 1976; Snape, 2004; Swaminathan, 2006). Gains in productivity between 1965 and 1995 have been in the order of 2% per annum for maize, wheat and rice (Evenson, 2003a; Pingali and Heisey, 1999), though rates have declined in the last decade. Similarly, productivity measured as total factor productivity (TFP) has also increased in rice, wheat and maize (Evenson, 2003a; Pingali and Heisey, 1999). In rice, TFP increased rapidly initially and then declined to 1.2% per annum, whereas in maize and wheat TFP has remained at about 2% per annum over the last 30 years. The impact of crop improvement AKST on non-cereals has been less well documented as these are often far more diverse, occupy smaller areas globally and are not traded as commodities. For example, legumes in total occupy an area of 70.1m ha globally, but there is a greater diversity of legume species used with clear regional preferences and adaptation (e.g. cowpeas (*Vigna unguiculata*) in West Africa, pigeonpea (*Cajanus cajan*) and mung bean *(Vigna radiata*) in India). Nonetheless, plant breeding has raised yields in many protein crops (Evenson and Gollin, 2003b).

Biotechnology, in the form of genomics and Marker Assisted Selection/Backcrossing (MAS/MAB) as well as transgenic technologies, is only now beginning to impact on plant breeding

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,2	C	0 to +5	G	All crops

The rapid expansion in genomics and related technologies is only now beginning to impact on plant breeding (Baenziger et al., 2006; Swamininathan, 2006). At present, the principal use of genomics in plant breeding is for MAS/MAB to pyramid disease resistance genes (e.g. downy mildew resistance in pearl millet: ICRISAT, 2006) or to identify and incorporate quantitative traits such as root characteristics not easily manipulated by conventional breeding (Tuberosa and Silvi, 2006, Steel et al., 2006). MAS still remains too expensive to use widely in breeding programmes with thousands to tens of thousands of progenies to be screened, though organisations such as CIMMYT in Mexico are using selected markers on a regular basis (Reynolds and Borlaug, 2006). MAS can, however, shorten the breeding cycle substantially (ICRISAT, 2006) and the economic benefits of this are substantial (Pandey and Rajatasereekul, 1999).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

1,3,6	A	-2 to +5	G	Widespread applicability

For example, 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) is attributed equally to advances in breeding and to improved crop and soil management. In Latin America yield has increased by 136%, with 36% attributable to MVs and 64% other inputs (Evenson and Gollin, 2002). 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 impact of crop genetic improvement (CGI) on productivity. CGI has had a large impact on productivity, particularly in developed countries and in Asia (Figure 3.8). Much of this impact can be attributed to IARC CGI programmes, both direct (i.e. finished varieties) and indirect (i.e. parents of NARS varieties, germplasm conservation) (Evenson, 2003d). A recent study of CGIAR research (Raitzer, 2003) has shown substantial benefit-cost ratios for CGI research of between 2 (significantly demonstrated and empirically attributed) and 17 (plausible, extrapolated to 2011). Two innovations – MVs of rice (47% of benefits) and wheat (31% of benefits) account for most of the impact using the most stringent criteria. Benefits can also be demonstrated for many other crops. For example, an analysis of the CIAT bean (*Phaseolus vulgaris*) breeding programme (Johnson et al. 2003) showed that 49% of the area under beans could be attributed to the CIAT breeding programme, raising yield by 210 kg ha^{-1} on average and giving added value to production of $177 m. For Africa, where the breeding programme started later, about 15% of the area is under cvs that can be attributed to CIAT, with an added value of $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.

Figure 3.8

Adoption and impact of modern varieties (MV) has been less in sub-Saharan Africa (SSA) and Middle East and North Africa (MENA).

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,3,6	C	0 to -3	G	Mainly smallholder agriculture

In SSA and MENA, MV have been produced throughout the 1960s and 70s but these were not adopted (Evenson, 2003d). For example, the most popular peanut cultivars in Andhra Pradesh and Maharastra, India, are landraces such as TMV2 from the 1940s (Bantillan et al. 2003), and until very recently few if any MVs better than these had been bred. In some cases, MVs were not better than TVs in terms of adaptation and especially organoleptic qualities. However, in many cases the failure of MVs to be adopted was the result of poor formal-sector seed systems failing to deliver MVs to farmers, rather than a lack of improved varieties (Witcombe et al., 1988). Poor seed systems remain a major constraint in many parts of Africa (Tripp, 2001).

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
1, 3, 6	C	-1 to -3	G	High and low potential systems

Although many 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 because the MV is unsuitable. 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 MV may also vary with environment, with lower rates of turnover (less temporal diversity) 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 in the order of 1 to 2%, then farmers may be loosing 16 to 30% of potential yield; and these losses will be even higher where MVs have superior disease or pest resistance.

Although high potential environments, particularly irrigated rice and wheat environments, gained the most in terms of productivity growth from MVs, less favorable environments have benefited as well.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 6	B	+1 to +2	G	Low potential environments

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

There is growing concern that genetic yield potential is not increasing

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	C	+1	G	Widespread

Plant breeding in developed and less developed countries has to date been hugely successful at delivering new, higher yielding varieties year-on-year (see Fig. 7), largely through better adaptation, greater partitioning of biomass to seed (i.e. Harvest Index; Austin, et al, 1980, 1989; Sayre et al., 19971999) and disease resistance. For example, in UK winter wheat the above-ground biomass of an old variety, Squareheads Master (introduced in 1920s) and a modern variety Brimstone (1985) was identical at about 12 t ha^{-1} at nitrogen levels from 0 to 288 kg ha^{-1}; yield, however, varied from 4.9 to 8.3 t ha^{-1} giving HI of 0.43 and 0.70 (Austin et al., 1993). However, under conditions where pests are efficiently controlled and there are no limitations to the supply of water and nutrients, evidence (Figure 3.9) suggests that the yield potential of the most productive rice, wheat, and maize cultivars has not markedly increased since the major advances of the Green Revolution (Peng et al., 1999; Sayre et al., 2006; Duvek and Cassman, 1999). Even in the UK, where the benefits of plant breeding have been well documented (Silvey 1984, 1999), national wheat yields are at best only increasing slowly (Sylester-Bradley et al., 2005), although in any given year yields of the best varieties in National Recommended List trials with full protection nonetheless show average gains >2% per year above the most recently released varieties (which act as controls) (Austin, 1999; http://www.hgca.com/content.template/23/0/Varieties/Varieties/Varieties%20Home%20Page.mspxIt is also clear that in a number of annual grasses and legumes, where HI are approaching their theoretical maximum, that selection for increased total crop biomass and/or the exploitation of hybrid vigour will be important. Hybrid rice, which yields about 15% more than conventionally bred rice, is already grown on some 15m ha in China, about half the total area (Longping, 2004), and hybrid sorghum shows similar promise.

Figure 3.9

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 6	B	-2 to +2	R	Not clear

In contrast to the above concerns about limited future opportunities for yield improvement in cereals, there are some examples of continued yield increases. For example, coordinated efforts to improve management practices and profitability of Australia rice systems increased productivity from 6.8 Mg ha^{-1} in the late 1980s to 8.4 Mg ha^{-1} by the late 1990s (FAO, 1999c). 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 by the FAO (2003) suggests that rice productivity could be increased by 1.5 Mg ha^{-1} (ca. 50%) without exceeding the 80% criteria commonly used to establish the economically-exploitable component of the biophysical yield potential (Figure 3.10).

Figure 3.10

Poor basic management practices, often in combination with limited access to inputs and modern varieties (MVs), constrain the productivity of many smallholder- farming systems in developing countries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,3,4, 6	A	-2 to -5	G	Smallhoders in developing countries

In upland rice systems in Laos, Saito et al. (2006) demonstrated the importance of the adoption of improved varieties and N fertilization. By substituting MVs for traditional landraces, rice yields could be doubled to 3.1 Mg ha^{-1} with a moderate dose of nitrogen fertilizer further improving yield by 1 Mg ha^{-1}. Among farmers in Nepal, Regmi and Ladha (2005) suggest that modern crop management practices (e.g. timely establishment, precision planting, two weedings) together with site-specific nutrient management could boost rice productivity by 2 Mg ha^{-1} over typical farmer practices. In West Africa, rural surveys conducted by Wopereis et al. (1999) show that most farmers have limited knowledge of soil fertility management and of optimal establishment practices for rice. In these areas, nitrogen deficiency, inadequate weeding, and late planting are commonly associated with low cereal productivity (Becker and Johnson, 1999; Becker et al., 2001). 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).

Gains in yield per unit area per year are expected to remain lower than historically.

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

Conceptually, crop improvement goes through stages of domestication to produce Traditional Varieties (TVs), and then the replacement of TVs by a succession of MVs (Figure 3.11). In wheat, rice and maize gains were initially much higher when MV replaced traditional varieties (Figure 12: MV1 cf TV), in the range 35 to 65%. Subsequent gains when MV2 replace MV1 have been lower, between 10 and 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 effort goes into maintaining resistance and not just raising yield potential (Baenziger et al. 2006; Legg 2005). Others have argued that constraints due to soil fertility and structure, and diseases and pests from continuous cultivation now limit increases in yield potential (Cassman et al., 2003). Nonetheless, further small gains year on year are expected, though 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 $\times$ E or local adaptation.

Figure 3.11

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2	E	+1	R	India

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

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 4, 5	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 and resulted in mean annual increments averaging 35m^3 ha^{-1} a^{-1}, compared with 20-25m^3 ha^{-1} yr^{-1} from selected provenances, and about 12m^3 ha^{-1} a^{-1} from unselected seedlots (Delwaule, 1983). In Brazil, mean annual increments between 45-75m^3 ha^{-1} yr^{-1} and up to 90m^3 ha^{-1} yr^{-1} have been recorded (Campinhos, 1999). The development of clonal approaches requires wise strategies for clonal development (Leakey et al., 1987; Ahuja and Libby 1993 a/b), genetic diversity (Leakey, 1991), deployment (Foster and Bertolucci, 1994) and silviculture (Evans and Turnbull, 2004; Lawson, 1994) to maximize gains and minimize the risks of pests and pathogens 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).

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
3, 4, 5	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 the capacity to root have seemed 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, 2005) have resulted in some principles, which have wide applicability (Dick and Dewar, 1992) and explain some of the apparently contradictory published information (Leakey, 2004).

3.2.1.2.2 Breeding for adaptation and abiotic stress tolerance

Progress in breeding for marginal environments has been slow.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	+1	R	Widespread aplicability

Crops and plants, especially in marginal environments, are subjected to a wide and complex range of abiotic stresses, most notably poor soils (availability of macro- and micro-nutrients, acidity, structure, salinity), and extremes of both soil moisture and air/soil temperature. Progress in breeding for such environments 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, the soil environment and the aerial environment (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
1	D	+1	R	WANA, SSA

Breeding for marginal and stressed environments has not been easy, especially where wide-adaptation was also important. However, breeding programmes that make full use of locally-adapted germplasm and TVs (Ceccarelli), and select in the target environments (Cecarelli, Banziger et al. 2006) have been successful. For example, in Zimbabwe, where maize is subject to low soil fertility and drought stresses, Banziger et al. (2006) have shown how the careful selection of test environments (phenotyping) and selection indices can increase yields across Zimbabwe and regionally. Their principles were to give equal weight to three selection environments (irrigated, drought stress, N-stress), to use fairly severe stress environments, and to use secondary traits with higher heritabilities to improve selection under stress. In multi-location 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
1	B	+2	G	Many crops

Yield is the integration over the life of a crop of many processes, 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 period centered around flowering), have been identified (Hall, 1992; Vara Prasad et al., 2005; Craufurd et al., 2003) and in some cases genes identified and heat tolerant varieties bred (Hall, 1992). These particular responses will be increasingly valuable as climate changes. Likewise, in rice QTLS and genes for salt tolerance, submergence tolerance and P-deficiency have been identified through QTL and transcriptome studies, and these are currently being used in breeding programmes (Xu et al., 2006; Ismail 2006). Another important and specific mechanism is developmental escape; in maize, for example, a short anthesis-silking interval (ASI) is a very important drought tolerant trait (Bolanos and Edmeades, 1996). A number of other drought tolerance traits also show some promise – C^{13} isotope discrimination, osmotic adjustment, stay-green - and genomic studies as well as breeding are underway (Tuberosa and Silvi, 2006). Nevertheless, even if these traits are expressed under field conditions, it remains to be proven if they confer a substantial degree of stress tolerance and higher yield.

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
1	B	0 to +3	G	Many crops

The use of genomic-based breeding approaches are already widespread (e.g. Generation Challenge Programme: http://www.generationcp.org/index.php), particularly Marker Assisted Selection (MAS) or Backcrossing (MAB). CIMMYT, for example, routinely uses five markers and performs c. 7000 marker assays per annum (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). Using MAS, it took just over three years to introduce resistance compared with nearly nine years by conventional breeding. 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, 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 impact plant breeding

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 to +2	G	Widespread applicability

The genome of the model plant species Arabidopsis and its function has 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* and flowering pathways understood (Hayama and Coupland, 2003; Corbesier and Coupland 2005; Bernier and Perilleux, 2005) and modelled (Welch et al. 2003; Locke et al. 2005). Homologues of key flowering pathway genes have been identified in rice (the model cereal) and many other crop plants, and flowering pathways and the control of flowering time better understood as a result (Hayama and Coupland, 2004), offering the opportunity to manipulate this pathway. Drought reistance has also been studied in Arabidopsis and two genes, the DREB gene (Pellegrineschi et al., 2004) and the *erecta* gene (Masle et al., 2005), confer some tolerance to water-deficit or increase water-use efficiency (WUE). Constructs of the DREB gene have been produced in rice, wheat and chickpea, showing some promise (Bennett, 2006).

Irrespective of the success or otherwise of GM crops in raising yield or increasing disease and pest resistance, these approaches will not remove or replace the need for traditional crop breeding, release and dissemination processes.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	A	+2	G	Widespread applicability

Ultimately, 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. Therefore the same constraints to adoption by farmers apply, whether GM or not. 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. For example, in India a new version of a widely grow pearl millet variety HHB67 incorporating resistance to a new and emerging race of downy mildew (identified by DNA finger-printing and incorporated using MAS backcrossing), was approved for release (ICRISAT 2006, DFID, 2005). Additionally, only a few countries currently have biosafety legislation or research capacities that allow for the testing of GM crops.

3.2.1.2.3 Bioenhancement

Breeding for improved and enhanced quality is increasingly important

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2	C	+1	G	Maize, rice

Traditionally, breeding was very much concerned with yield, adaptation and disease/pest resistance rather than quality and post-harvest processing traits. In recent years, far more emphasis has been given to quality, especially user-defined quality (i.e. consumer acceptance), industrial processing and now bio-enhancement. In particular, more breeding programmes are now focusing on fodder and forage quality, and not just grain quality. Bio-enhancement or bio-fortification is not a new concept (CIMMYT has worked on quality protein maize (QPM) for more than two decades), but concerns over micro-nutrient deficiencies (Bouis et al., 2000; Graham et al., 1999; www.harvestplus.org) in modern diets are driving this. Vitamin A deficiency, for example, impacts 25% of all children under 5 in developing countries – some 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, making 'Golden Rice' (Guerinot, 2000), and efforts are underway to produce micronutrient-dense iron and zinc varieties in rice. It is a matter of debate whether this is a better approach than diversifying the farming systems with fruits and other products, that diversify the diet, provide the extra nutrition, and which potentially are cash crops that diversify the sources of income and makes the farm ecologically more sustainable. Existing traditional varities of crops with higher vitamin A (e.g. existing traditional golden or red rice cultivars) or micronutrient contents have often been neglected in both government promotion for nutrition and by breeding organisations. Many of these varieties have been displaced in farming systems by adoption of modern high yielding varieties.

3.2.1.2.4 Genetic engineering/transgenes

Irrespective of the success or otherwise of GM crops in raising yield or increasing disease and pest resistance, these approaches will not remove or replace the need for traditional crop breeding, release and dissemination processes.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	A	+2	G	Widespread

Ultimately, 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. Therefore the same constraints to adoption by farmers apply, whether GM or not. 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. For example, in India a new version of a widely grow pearl millet variety HHB67 incorporating resistance to a new and emerging race of downy mildew (identified by DNA finger-printing and incorporated using MAS backcrossing), was approved for release (ICRISAT 2006, DFID, 2005). Additionally, only a few countries currently have biosafety legislation or research capacities that allow for the testing of GM crops.

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.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 6	C	Not yet known	G	Widespread

Biotechnological discoveries include novel technologies like: tissue culture of cells *in vitro*; the use of molecular markers within the genetic code to explore the genome (genomics); injection of nucleic acid into cells or organelles; recombinant DNA techniques (cellular fusion beyond the taxonomic family and gene transfer between organisms) (CBD, 2000). Such recombinant DNA injected into cells or organells (often referred to as 'transgenes') consist of a number of DNA sequences assembled from different organism (called 'transgene constructs') These technologies are advancing rapidly and now the FAO BioDEC database includes about 2000 entries from 70 developing countries (http://www.fao.org/biotech/inventory_admin/dep/default.asp) and a number of GM crop plants and animals have been developed, and some of these are being developed commercially.

Genetically Modified crops are being produced and marketed by commercial companies, and grown in a limited number of developed and developing countries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 6	C	Not yet known	R	Controlled by government regulation

The most widely used GM crop plant in commercial agriculture is herbicide-resistant soybean. The International Service for the Acquisition of Agri-biotech Applications (ISAAA) has reported that the global area planted to approved Genetically Modified (GM) crops in 22 countries is 102 million ha in 2006 (James, 2006), with 53% in USA, 18% in Argentina, 11% in Brazil, 6% in Canada 3.7% in India and 3.5% in China. Eleven of these countries are developing countries (eg. Paraguay, India, South Africa). In Europe, GM crops (mostly maize) occupy only small areas, with Spain being the largest (0.1 million ha). Overall, 95% of all GM crops are grown in only 6 countries (Herdt, 2006; James 2006). The overall most important GM crops are soybean (57% area), maize (25%), cotton (13%) and canola/oilseed rape (5%). Most GM crops by area have added herbicide tolerance (68%), contain the Bt-gene for insect resistance (19%), or a combination of both (13%). However, GM crop trials are underway for a large number of other traits.

Public concerns and contradictory reports about socio-economic, legal and ethical implications have constrained the wide assessment and commercialisation of GM crops.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	C	Not yet known	G	Widespread

Despite the rapid scientific advances, the uptake of these technologies has been constrained by public and governmental concerns about their environmental, socio-economic and health impacts of genetic modification on related wild species with which GM individuals may breed, and on concerns about biosafety and health impacts Independent broad-based evaluations have been initiated to determine their current benefits and costs regarding their environmental (Squire et al., 2005), socio-economic (Herdt, 2006) and health impacts. Studies in USA, India, China and South Africa, have shown positive economic and environmental benefits due to GM pest-resistant varieties, both through yield gains and a reduction in pesticide use with concomitant improvements in farmer’s health from the reduction of pesticide poisoning (Gianessi, 2001; 2002; Bennett et al., 2004ab; Pray et al., 2002; Qaim and Zilbermann, 2003; Morse et al. 2004). Qaim and Zilberman analyzed trial data from seed companies testing Bt-cotton and concluded that quantities of insecticide can be reduced by about one third relative to conventional (non-Bt) varieties, and yield gains can be up to 80% in seasons with bad bollworm infestations. Following the approval of Bt-cotton in India in 2002, ‘unofficial’ Bt-cotton cultivars arose from intended or accidental outcrossing of the Bt-transgene to popular cotton varieties, fuelling concerns about the stability of yields and resistance (Morse et al., 2005).

Recent studies are challenging the earlier optimistic claims for the benefits of Genetic Modification technologies in particular regarding their impact in developing countries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	C	-3 to +3	G	Concerns high for developing countries

Studies implemented since the implementation of GM technologies and field trials have concluded that there has been relatively little contribution to increased food production, nutrition, or the income of farmers in less-developed countries (Herdt, 2006). Another evaluation of global GM technology in the last decade has concluded that small-scale farmers have benefited little, with many being worse off than before (Friends of the Earth, 2007). The number of small scale farmers in S-Africa growing GM crops has actually declined in Kwazulu Natal. Numbers of smallholder farms hit record lows from 2002 to 2005 and cotton production decreased from over 90000 ha in 1996/97 to about 22000 ha until 2005/06, with an estimated further reduction of 20% in 2006/07 (Friends of the Earth, 2007). Others have concluded that this poor adoption of GM cotton represents issues of farmer choice (Witt et al., 2006) a failure to generate sufficient income in agroecosystems without a high level of intensification. In China, a study by Cornell University (Wang et al., 2006) found that the net revenue of hundreds of Bt farmers was significantly lower than that of non-Bt farmers in 2004, due to the emergence of secondary pests such as mirids, and the need for Bt cotton farmers to spray 15-20 times more pesticide than was previously needed. Pest problems and low yields have similarly been a problem in India (Morse et al., 2005), due to declining Bt-expression in maturing plants. In addition, uncontrolled out-crossing of the Bt-transgene into other local varieties has lead to low quality Bt-cotton cultivars providing insufficient control of the main target pests (Morse et al., 2005). Smallholder farmers who bought the very expensive Bt-cotton seeds are now suffering from debt and bankruptcy. High suicide rates have led the Indian local and national government/s to take action (Sharma, 2006a,b), and a legal case is currently pending in the Indian Supreme Court. In Argentina, socio-economic and environmental problems have arisen from the cultivation of HR soybean. Reports indicate dramatic land use changes involving large-scale displacement of farm labor, and an increase in the number of large farms at the expense of small family farms (Benbrook, 2005; Joensen et al., 2005; Pengue 2005).

Reports on the environmental impacts of GM crops are inconclusive and contradictory and mostly limited towards chemical-intensive, low-diversity cropping systems.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	Not yet known	G	Worldwide

The Ecological Society of America (2005) has concluded that little research has been done to examine the fundamental issues related to environmental consequences, risk assessment and post-release monitoring and detection of GM plants in the countryside or their unintended impacts on population genetics of wild or semi-domesticated relatives (Snow et al., 2005). In addition, the experimental designs of some studies have been questioned (Marvier, 2002). Genetic contamination, intentional or unintentional transgene flow, is thought to possibly introduce traits such as herbicide and insect resistance traits into wild and weedy relatives (e.g. Snow et al. 2003, Squire et al. 2005), so increasing their invasiveness by making them more difficult to control or allowing them to spread more aggressively. Further, a recent review of reported non-target effects when exposed to Bt crops or pesticides reported that in over 50 evaluated laboratory studies, more than half showed adverse effects (Hilbeck and Schmidt, 2006). However, research is still needed to explain the reported effects and what the potential consequences these effects may have in long-term field trials. One possible consequence involves the emergence of secondary, non-target pests as seems to happen currently in China (Wang et al., 2006). Field experiments on the impacts of Bt crops on nontarget organisms are to date inconclusive due to constraints like field size, replicability in space and time, natural variability of abiotic and biotic factors. Most studies are conducted in monoculture systems in which over 90% of all GM crops currently are grown (Cattaneo et al., 2006**).** Consequently the results have limited applicability to low-input, smaller-scale systems with high biodiversity. Current risk assessment concepts and testing programs for regulatory purposes are limited to a few representative species and largely following the testing protocols for chemicals, such as pesticides (Andow and Hilbeck, 2004). Improved assessment concepts are being developed but are only beginning to be implemented (Hilbeck et al., 2004; 2006).

Currently there is little if any information on ecosystem biochemical cycling and bioactivity of transgene products and their metabolites, like those of Bt-toxins, spreading in above and below ground ecosystems.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	Not yet known	G	Widespread

Some recent studies have confirmed the expected spread of Bt-toxins through food chains in the field (Harwood et al. 2005, Zwahlen and Andow 2005). Bt-toxins enter the ecosystem via multiple routes. For example, embedded in living and decaying plant material, as toxin leaching and exudated from roots, pollen, faeces from insects and other animals such as cows fed with Bt-maize feed. The presence of Bt toxin metabolites in faeces of cows was confirmed (Lutz et al. 2005). Several experiments studied the impact of Bt-crop plant material on soil organisms with variable results ranging from some effects to transient effects to no effects (e.g. Blackwood and Buyer 2004; Zwahlen et al. 2003). However, no study exists to date studying the ecosystem cycling of Bt toxins and their metabolites nor 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
4	C	Not yet known	G	Widespread

Within the last decade there are reports of 12 weed species increasing from none in 1995 that have developed resistance against ‘glyphosate’, the main broad spectrum herbicide used in GM crops. These reports come from countries where herbicide-resistant GM crops are grown (Heap 2007, van Gessel 2001, Owen and Zelaya 2005) and the use of glyphosate has greatly increased since the introduction of herbicide tolerant crops. To date, no resistance management plans are required for the production of herbicide-resistant crops. In contrast to herbicide resistant crops, resistance management strategies are required for Bt-crops with insect resistance, in the countries growing them. To date, there has been only one report showing resistance in insect pests against one of the commonly used Bt-toxins (Gunning et al. 2005). These findings indicate a need for efficient resistance management strategies and further monitoring of the spread and impacts of GM-resistance genes in populations of weed and pest species.

The illicit spread of GM crops undermines regulations and poses threats to agriculture and wildlife.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 3, 4, 5	C	Not yet known	G	Worldwide

There have been reports of over 100 cases of GM-contamination and another 27 cases of illegal GM-releases in some 40 countries over the past 10 years, especially since 2000 (GM Contamination Register – Report 2007). The majority of these reports involved GM maize. These reports, in particular the one involving the spread of unapproved traits from GM rice field trials in the US and China in 2006 deliver several important lessons: i) the currently applied containment strategies are not working reliably, ii) transgenes are escaping and can spread rapidly around the world, iii) the major problem of long-distance spread is anthropogenic (food and feed transportation and processing pathways) and is not through natural processes. In addition there have been incidents when a grain approved for animal feed transferred unofficially into human food processing, hightlighting a loop-hole in the regulations and insufficient separation in the food transport and processing chain for human food and animal feed. These incidents undermine national and international biosafety legalislation and regulation requiring prior informed consent and risk assessment for all 139 member states to the Cartagena Protocol on Biosafety, and pose a serious threat to GM-free crop production, whether for market reasons or conservation concerns. This issue will become particularly important with the field testing and commercialization of GM crop plants for pharmaceutical and industrial compounds.

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
1, 4, 6	C	Not yet known	G	Widespread applicability

Progress has been made in developing transgenic technologies in animals. This has enabled a focus on the improvement of disease resistance by 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 for this to happen. In addition to some current lack of knowledge about which are the candidate genes to transfer, there are ethical and animal welfare concerns in many countries, and a lack of consumer acceptability in some countries. Another constrain to progress is the lack of an appropriate industry structure to capitalise on the technologies, and high cost of the technologies.

GM technology is being used to develop strains of genetically modified fish for potential use in aquaculture.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 5, 6	C	Not yet known	G	Worldwide

To date, at least 10 species of fish have been modified for enhanced growth, including the common carp, crucian carp, channel catfish, loach, tilapia, pike, rainbow trout, Atlantic salmon, Chinook salmon, and sockeye salmon. These however are yet to be approved for commercialization (Aerni, 2001 as cited in Delgado et al., 2003).

3.2.1.2.5 Advances in ICT

Innovations in information technology have been essential for progress in biotechnology

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

Genomics, proteomics and metabolomics generate vast quantities of data that require huge computing power and database storage capacity to utilize effectively, and advances in ICT have been fundamental to this. The growth of the worldwide web has allowed these data to be widely accessed and shared, increasing their impact. The complexity and size of tasks such as describing the genome of model plants including rice has led to global collaboration and data-sharing.

Climate and crop modeling is positively affecting crop production

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	+2	G	Widespread

The increasing availability of climate data and the use of simulation models, globally, regionally and locally, is having a positive impact on agricultural production. At the scale of the crop or field, crop growth and yield simulation models can help define breeding traits, define growing environments and analyze G x E interactions (van Oosterom et al, 1996; Muchow et al., 1994; Sinclair et al. 2005). At a larger scale, global and regional climate models (GCMs and RCMs) are producing more skillful forecasts and there is considerable collaboration between meteorologists and crop scientists to produce seasonal weather forecasts (Slingo et al., 2006; Sivakumar, 2006). These forecasts range from months to weeks (examples) and have proved of considerable practical and financial benefit in countries such as Australia (Stone, 2006). However, more attention needs to be given to delivering the forecast to users, especially farmers. These approaches are going to become far more important as climates change and variability of seasonal weather increases, both for farmers but equally for policy-makers and institutions.

Remote sensing and site-specific management benefit from ICT AKST

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	+2	G	Widespread

Already site-specific management or precision agriculture benefits from ICT ASTs (Dobermann et al., 2002; Dobermann and Cassman, 2002) and advances in remote sensing will enable further progress to be made.

3.2.1.3 Genetic improvement in 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
1, 2, 3	A	0 to +4	G	Widespread applicability, mostly in developed countries

There has been widespread use of breed substitution in developed countries and some developing countries, often leading to the predominance of a few, very specialized, breeds, and often pursueing quite narrow selection goals. Organised within-breed selection has been practised 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 widespsread in commmercial production, exploiting complementarity of different breeds or strains, and heterosis or hybrid vigour (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
1, 2, 3	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 (BLUP) 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 focussed 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 programmes 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
1, 2, 6	B	0 to +3	G	Developing countries

The gains in productivity per animal have been greatest in developed countries, and in the more ‘industrialised’ 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, which 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.

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
1, 4, 6	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. So, when these techniques are used, it is necessary to check that the expected benefits are actually being 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 achieveing, relevant, cost-effective, publicly acceptable breeding programmes.

The recent advancement of aquaculture is mainly due to advances in induced breeding or artificial propagation techniques - hypophysation.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 5	B	-2 to +3	G	

This has particularly occurred in the carp polycultures and in freshwater fish farming in rice fields, seasonal ditches, canals and perennial pond**s.** However, in Bangladesh, it has recently been reported that hatchery-produced stock mainly of the carps, have shown reduction in growth and reproduction performances, increased morphological deformities, disease and mortalities, etc. These are probably due to genetic deterioration in the hatchery stocks as a result of poor fish brood stock management, inbreeding depression, and poor hatchery operation (Hussain and Mazid in Penman, Gupta and Dey, 2005).

3.2.1.4 Manageing for biotic stress tolerance

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 6	A	-2 to -5	G	Widespread

In many developing countries, hand weeding remains the most economical and prevailing practice for weed control. On smallholder farms in these regions, estimates suggest that more than 50% of total labor dedicated to the farm enterprise is devoted to hand weeding (Ellis-Jones et al., 1993; Akobundu, 1996). Despite these labor investments, crop losses to weed competition are nearly universally identified as sizeable production constraints, typically causing yield reductions on order of 25% in smallholder agriculture (Parker and Fryer, 1975).

For crops like cowpea and maize in Africa, the parasitic weed *Striga gesnerioides* can cause yield losses that range from 15 to 100% (Boukar et al., 2004). 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 countries like Vietnam where the price of labor is rising (Auld and Menz, 1997). Even in areas that employ herbicides, yield losses are substantial; estimates in the early 1990s suggested that annual losses of US$4 billion are caused by weed competition in the agricultural systems of the United States. Moreover, herbicides are a prodigious financial liability for producers, with expenditures typically constituting 20 – 30% of total input costs in industrialized countries (Derksen et al., 2002).

Intensive herbicide use has lead to concerns for sustainable use and environmental quality

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 6	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: herbicide resistance is documented in 313 weed biotypes (www.WeedScience.org, viewed 3/1/07), traces of 'Atrazine' and other potential carcinogens are routinely documented in ground and surface water resources in industrialized countries (United States Geological Survey, 1999), and on a global scale the quantity of active ingredient applied as herbicide as well as the energy required for manufacturing and field application is larger than all other pesticides combined (FAO, 2000). 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). 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 herbicide resistance crops (HRCs); with HRCs farmers 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.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 6	A, 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 assemblage. The first line of defense against weeds is a vigorous crop and numerous studies have demonstrated the importance of basic crop management and cultural practices that 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), along with simple management changes like higher seeding rates, spatially-uniform crop establishment (Olesen *et al*., 2005), and banded fertilizer placement beneath the crop row (Blackshaw *et al*., 2004) can reduce crop losses from uncontrolled weeds and, in some cases, reduce dependence on herbicides. In conventional production settings, few of these options have been explicitly adopted by farmers. Several authors have suggested that cultural practice innovations for weed control will work best if they are compatible and efficient complements to existing agronomic practices. In line with this view, Norris (1992) suggests that researchers need to pay closer attention to the need and constraints of farmers as they develop new options for weed management.

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
1	B	-1 to -4	G	Smallholder agriculture

Parasitic weeds such as *Striga* spp., *Orobanche* spp., and *Alectra vogelii* are major production constraints to several important crops, especially maize, sorghum and cowpea in SSA. *Striga gesnerioides* is widely spread in Africa and can cause 100% yield loss. Genes conferring resistance to *S. gesneroides* and *A. vogellii* have been identified using Amplified Fragment Length Polymorphism markers (Boukar et al., 2004) and successfully deployed in cowpea (Singh and Emechebe, 1997), and identified and mapped for *Orobanche* resistance in sunflower (Tang et al., 2003). Host-plant resistance has been harder to find for *Striga hermonthica* and *S. asiatica* are in maize and sorghum in SSA, but 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 ands sorghum in West Africa is rotation and trap-cropping, using legumes, especially soyabean, to germinate *Striga* seeds.

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
4	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, Wilcove et al. 1998) 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

$US28-45 million, or approximately 40% of the Philippines' annual expenditure on rice imports (Naylor 1996). Move to biotic, weeds

The late 20th 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
1, 2, 3, 5	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, that have provided effective worldwide protection against epidemic losses from wheat rust over the past 40 years (CIMMYT, 2005; Pretorious 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 it is predicted 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 is a threat to a staple crop vital for food security.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	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 AKST with the future emergence of new and highly virulent geminivirus diseases (Legg and Faquet, 2004). Cassava is important to future food security in Africa. The hardiness of this crop under normally low disease-pressure conditions, and its minimal crop management requirements allows cassava to function as an emergency crop in conflict zones (Gomes, et al., 2004), and could be an 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
1	B	+1 to +4	G	USA, WANA

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 approach has been taken to Russian wheat aphid, *Diuraphis noxia* in wheat and barley in USA (Mornhinweg et al., 2006), and to soybean aphid (*Aphis glycines*) (Mensah et al., 2005).

Resistance to grain storage pests prevent yield and quality losses

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2	B	-1 to -5	G	Smallholder agriculture

Storage pests lower the quality of the stored grain and seeds, especially where 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 affects legumes like cowpea (Dhliwayo et al., 2005).

3.2.1.5 Advances in soil and water management

Traditional fallows used to increase the carrying capacity of the land in a sustainable way, but are seldom found now.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	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, rebuilding a permanent plant cover of the soil surface, improvement of soil permeability by root activity and the return of organic matter to soil, protection against erosion by heavy tropical rain and wind, protection of the soil from direct radiation and warming, restoration of biodiversity, etc (Swift and Anderson, 1993; Swift et al., 1996; Buck et al., 1999). Natural fallows of this sort are no longer applicable in most places because population pressures on available land are too high, consequently shorter and more efficient fallows using leguminous shrubs and trees have be developed (Kwesiga et al., 1999). When soil fertility is severely depleted, some external mineral nutrients (phosphorus, calcium) or micronutrients may be needed to hasten 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
2, 3, 4, 6	E	-5 to -2	G to L	Widespread

Extent of soil degradation and the loss of fertility is much greater in tropical than in temperate areas. Net nutrient balances (kg/ha 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 enterprise 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 with one another. 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 must be accomplished at the farm- or field-scale through 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, nitrogen use efficiency (NUE) for cereal production is approximately 33% (Raun and Johnson, 1999). Many systems are also 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
1, 3, 4	A	+1 to +3	R	Especially important in the tropics

In the tropics, the return of crop residues at a rate of 10-12t dry matter ha^{-1} represents an input of 265kg carbon ha^{-1} in the first 10cm upper soil layer (Sá et al., 2001ab; Lal, 2004). Given appropriate carbon:nitrogen ratio, this represents an increased water holding capacity of 65-90mm, and potentially 5-12% yield of corn or soybean yield, and an increased income of US$40-80$ha^{-1}$ (Sisti et al., 2004; Diekow et al., 2005). When the soil is strongly degraded, no-till farming, conservation agriculture, agroforestry, fallows with nitrogen–fixing plants and cover crops, manure and sludge application and inoculation with specific mycorrhiza can be an effective way to rapidly increase soil organic carbon and vegetation cover/crop yield (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
1, 3, 4	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, perfect 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 United States, maize grain produced per unit of applied N increased by more than 40%, with a portion of this increase attributed to practices such as pre-plant soil tests to establish site-specific fertilizer recommendations and to the increasing use of split fertilizer applications (Raun and Johnson, 1999; Dobermann and Cassman, 2002). Despite improved management practices, average N recovery in U.S. 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
1, 3, 4, 5	B	0 to +2	N/R	Smallholder households of the semi-arid tropics.

Resource constraints prevent many smallholder farmers from applying fertilizer at rates that maximize economic returns. ICRISAT has been working in SSA to encourage smallholders 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. Micro-dosing involves the precision application of small quantities of fertilizer, typically phosphorus and nitrogen, close to the crop plant. This enhances fertilizer use efficiency and has been shown to improve the productivity of maize in Zimbabwe by approximately 30%. Yield gains are larger when fertilizer is combined with the application of animal manures, better weed control, and improved water management. To improve ease of delivery, which typically occurs when the maize is at the 5 to 6 leaf stage, recent innovations have focus on formulating the fertilizer as single-dose capsules.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 6	A, B, F	+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 cropping systems (Walters et al., forthcoming). In both intensified and low-yielding agricultural systems, there are strong justifications for exploiting the value of biological nitrogen fixation (BNF) from leguminous crops. 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, which remains in the field after harvest. In Zimbabwe, the impacts on sorghum performance of four grain legumes were assessed under semi-arid conditions. In both years of a two year experiment, sorghum grain yield following legumes was increased by more than 1 t ha^{-1} in contrast to yield achieved with continuous sorghum production (e.g. 1.62 t ha^{-1} to 0.42 t ha^{-1}). Other studies in Africa have also demonstrated the value of using grain legume like peanut as a partial solution for overcoming poor nitrogen fertility in the soil thorough BNF (Waddington and Karigwindi, 2001). However, degraded soils that are low in soil phosphorous may limit the effectiveness of BNF (Vitousek et al., 2002). In the United States, Varvel and Wilhelm (2003) estimate that soybean provides between 65 and 80 kg N ha^{-1} to subsequent grain crops and that fertilizer recommendations can be reduced accordingly. See also 'N-fixing trees' and 'Improved fallows' in Subchapter 3.2.2.1.7

Water management and increased productivity

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	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 (Figure 3.12): (i) basin water is 'blue' water and contributes to river runoff, and (ii) green water, which passes through plants is transpired (Falkenmark, 2000). Land-use changes are a means of reallocating green water and altering the blue–green balance. There are a number of different strategies by which farmers can improve water productivity values (production (kg) per unit of evapo-transpiration):- a) better timing of supplies or increasing the reliability of water supply. b) improved land preparation and fertilizer use to increase the return per unit of water, c) reduced losses to evaporation from fallow land, lakes, rivers and irrigation canals, (d) reduced losses from transpiration by non-productive vegetation, e) reduced deep percolation and surface runoff, f) minimized losses through salinization and pollution, g) reallocation of limited resources to higher-value users, and h) development of storage facilities (Molden, et al., 2003). The reallocation of water can have serious legal, equity and other social considerations that must be addressed. 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).

Figure 3.12

Micro irrigation techniques can improve crop yield while increasing factor productivity of water and labour, but sustained adoption rates can be low in the absence of effective technical support

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	B	+2 to +4	N/R	Smallholder households of the semi-arid tropics.

Small-scale, drip irrigation has the potential to improve yields, income, and household nutrition (reference from Asia?). Since 2002, some 70,000 low-cost, low-head drip irrigation kits have been distributed throughout the rural areas of Zimbabwe. A countrywide survey was undertaken in 2006 to determine the impacts of the drip kits that had been delivered to needy households. Survey results showed that after 3 years since introduction, only 16% of the kits were still being used. Reasons for poor adoption included a lack of water; poor understanding of the drip kit concept and the guidelines for appropriate use, and a lack of technical support and follow-up by NGOs and the national extension service to reinforce these guidelines. Results from this survey suggest that relatively complex technologies such as drip kits should be embedded in long-term developmental programs that involve both the public and private sector. This will ensure that appropriate technical support is provided in terms of crop water requirements, pest and disease control and the development of input supply chains for spare parts.

In semi-arid regions, soil modification techniques like basin planting can increase crop yields for smallholder farmers by concentrating water and nutrient resources

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	0 to +2	N/R	Smallholder households of the semi-arid tropics.

To reduce the quantities of water and nutrients used during crop establishment, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) with several NGO partners has promoted a ‘conservation agriculture’ package that is based on basin planting. The dimensions of these basins are approximately 15cm long, 15cm deep and 15cm wide and are prepared during the dry season when labour demands are relatively low. Basin planting works on the principle that rather than spreading nutrients and water uniformly over the field, they can be concentrated in small areas to maximize yield when resources are limited. For smallholder systems in dry areas of southern and western Zimbabwe, maize yields were 15 -72% (average = 36%) greater from basin planting than from conventional ploughing and whole-field cultivation.

3.2.1.5 Advances in post-harvest technology

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
1,2	A	+1to +3	G	Developed countries

These include canning, bottling, freezing, freeze drying, various forms of processing, etc. (UC Davis, 2006; Washington State University, 2006; FFTC, 2006), especially appropriate for large commercial enterprises. In addition, 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 have been examined (Brovelli 2006). Together these studies (Table 3.3) provided understanding on the sensitivity of micronutrient availability with the ways in which foods are handled, stored and cooked (Welch and Graham, 2000; Tsou *et al*., 1995; AVRDC, 1995; Augustin *et al*., 1985).

Table 3.3

3.2.2 Systems and approaches in support of sustainable integrated natural resources management

Since the mid 20th Century, there have been two relatively independent pathways to agricultural development. The first, which has dominated formal AKST, has been initiated globally and has involved public-sector agricultural research, international trade and marketing and international policy. The second pathway has come from the grassroots of civil society and involved locally-based innovations meeting the everyday needs of local people and communities. This pathway addresses the integration of social and environmental issues with agricultural production, and has its foundations in traditional farming systems. With the realization that the formal pathway was not leading to sustainable landuse 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 CGIAR Centres with natural resources mandates. These and other research initiatives have now given credibility to Integrated Natural Resources Management, in various forms (eg: agroforestry and ecoagriculture) and recognized the importance of, and need for, new scientific research agendas (INRM Committee of CGIAR - eg: Place and Were, 2003).

3.2.2.1 Integrated management systems

3.2.2.1.1 Techniques and concepts

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	A	0 to +5	L, R	Tools with wide applicability

The need for monitoring land use as an integral component of sustainable development projects is expressed throughout the literature (Janhari, 2003; Kerr, 2002; Panigrahy, 2003; Rao, 2003; Verma, 2003). Remote sensing and GIS technologies now available are used to cost effective monitor the impacts (short term and long term) of natural resource conservation and development programmes (Goel, 2003; Rao, 2003). While remote sensing using satellite imagery already provides useful monitoring and evaluation applications, improved use of higher-resolution data such as LANDSAT and SPOT imagery, consistent standardized methodologies, and field validation will help provide more consistent information (Millennium Ecosystem Assessment, 2005).

The increased spatial resolution of satellite images and recent technical progress in the use of geographical information systems (GIS) have stimulated new approaches to territorial development and agri-environmental management

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	A	0 to +5	L, R	Tools with wide applicability

High resolution satellite imagery and GIS technologies are tools for the spatial representation of land resources which are easily integrated in participative processes for natural resources management for studies of local sustainable development practices (Millington et al, 2001). They greatly enhance the long-term monitoring of environmental and social change, such as urbanization processes, deforestation or desertification, or the opening of new agricultural frontiers. Such evaluations are important in zones affected by conflicts or population displacement. Thus Imbernon (2005, 2004) has studied the spread of deforestation, the consequences of agricultural development in biological corridors and the impact of refugee populations on the environment in territorial development projects in ways that promote the collective management of the natural resources and evaluate the impacts of agricultural public policies.

Integrated Natural Resources Management (INRM) has provided opportunities for sustainable development and the achievement of IAASTD Development Goals.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	A	+1 to +5	R	Wide applicability

The concept of INRM 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 in Place and Were, 2003). It focuses on resolving complex real-world problems affecting natural resources in agroecosystems (Figure 3.13). These INRM innovations 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.

Figure 3.13

Resource-conserving agriculture involving integrated landuse systems has been demonstrated to benefit poor farmers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	+3 to +4	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 multi-locational study which covered 3% of cultivated land in 57 developing countries, identified very considerable benefits in productivity, while reducing pesticide use, enhancing carbon sequestration, increasing 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.

3.2.2.1.2 Integrated Pest Management (IPM)

IPM is based on effective management rather than complete elimination of pests.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	B	+1 to +4	L	Wide applicability

IPM is a means of managing pests and disease that simultaneously involves a number of different approaches to pest management, resulting in the growth of a healthy crop and the maintainance of the natural balance (Abate et al., 2000). Typically it involves the combination of genetic resistance, cultural measures for the promotion of natural agroecosystem function, and some chemical control measures. Hence, 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 control fewer fungicide treatments can be both much more effective and more economic. IPM is especially useful when crop values are too low to justify costly pesticide use. IPM provides a strategy for sustainably combating disease and insect problems, which is environmentally safe and preserves the natural enemies. This approach also reduces the risk of pest or disease organism developing resistance to the pesticide, by lowering the selection pressure imposed by spraying.

IPM is recognized as effectively controlling pests, diseases and weeds.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	B	+1 to +4	L	Wide applicability

Infectious and insect-borne animal diseases are becoming increasingly important, and may be related to unsustainable practices. IPM has become increasingly important in both developed and developing countries. It utilizes ecologically appropriate techniques and methods to maintain pest population below those causing economic injury (FAO, 1967). The past 20 years have witnessed IPM programs in many developing countries, although adoption is constrained by technical, institutional, social-economic, and policy issues. The future expansion of IPM in developing countries will depend on success in reducing such constraints and the better integration of science with farmer participatory approaches (Norton et al., 2005). Positive economic, social and environmental impacts of IPM are a result of lower pest control costs; higher levels of production and income and fewer health problems among pesticide applicators (Figure 3.14). IPM programs can positively affect food safety, water quality and the long-term sustainability of agricultural system (Norton et al., 2005). Agroforestry is an important component of IPM involving farm diversification and enhanced agroecological function (Altieri and Nicholls, 1999; Krauss, 2004).

Figure 3.14

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
1, 4	B	+1 to +3	L	Wide applicability

In contrast to strictly chemical approaches that tend to be prophylactic and uni-modal, integrated weed management makes use of ecological principals and strategies to control weeds (Swanton and Weise, 1991), and are typically knowledge intensive. 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), along with simple management changes like higher seeding rates, spatially-uniform crop establishment (Olsen et al., 2005), and banded fertilizer placement beneath the crop row (Blackshaw et al., 2004). For example, 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, that trigger the germination of the weed seed in the absence of the cereal host (reference). However, in general, herbicide use in agriculture has not been significantly 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 required for integrated management (Mortensen et al., 2000; Narkazo et al., 2005).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 4	B	+1 to +3	M-L	Wide applicability

The three major approaches to biological control are: importation, augmentation and conservation of natural enemies. The fungus *Metarhizium anisopliae* var *acridum* ‘Green Muscle’ ® is used to control the Desert Locust *Schistocerca gregaria* with good results (FAO, 2000y), while parasitoid wasps, *Encarsia formosa*, have successfully suppressed populations of whitefly (*Trialeurodes vaporariorum*) in greenhouses (Hussey and Scopes 1985, Parrella 1990), and the parasitic *Trichogramma* wasp has been successfully used as a for over 70 years, in more than 32 million ha of agricultural crops and forests in 19 countries annually (Li, 1994). *Trichogramma* are reared inside capsules over the winter and can be stored for later use in refrigerated conditions for up to nine months without loss of quality (Kabiri et al., 1990). The economic benefits of biological control can be substantial, for example cultures of the predatory mite, Metaseiulus occidentalis, with resistance to pesticides were used in California almond orchards and saved growers $24 to $44 /acre / year in reduced pesticide use and yield loss (Hoy 1992). The effectiveness of natural enemies is increased through cultural practices (Debach and Rosen 1991; Doutt and Nakata, 1973; Landis et al., 2000) that enhance parasitoid efficiency.

3.2.2.1.3 Integrated water resources management (IWRM)

IWRM takes account of the management of all natural aspects of water resources, in a participatory multi-sided way.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 4, 5	B	0 to +3	R	Wide applicability

Through participatory approaches, IWRM works with all sectors and stakeholders in water resource management to resolve the numerous conflicts associated with water use and management; resource development and environmental protection (Jaspers et al, 1999). This approach is beginning to identify the right balance between protecting the water resources, meeting the social needs of users and promoting economic development (Bury *et al,* 1999). Examples include the integration of participatory approaches within the development of alternate tillage practices to conserve water and low-cost technologies such as treadle pumps (Shah 2000), and water-harvesting structures, that provide access of water to the poor has a high poverty alleviation impact. The participatory process has integrated land, water and soil fertility management in a systems approach that recognizes that water use in agriculture, and especially irrigation water, meets the needs of fisheries, livestock, small-scale industry and the domestic needs of people, while enhancing ecosystem services (Bakker et al, 1999). Greater understanding is needed of the interactions between these multiple uses and their impacts on sustainable development.

The role of forestry in regulating water supplies for agriculture and urban areas has become increasingly contentious.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 4, 5	B	0 to +2	R	Wide applicability

Until recently, afforested watersheds were seen as ‘sponges’ which store and slowly release water, while deforestation led to flooding; landslides; downstream siltation of waterways, wetlands and reefs and water shortages. Now these processes have been recognized as a function of a far more complex set of relationships, in which the forests role is a site-specific function of slope, soil type and surface cover, associated infrastructure and drainage, groundwater regimes, and rainfall frequency and intensity (Calder 2005). However, water quality (as opposed to quantity) from forest catchments is still recognized as better than that from most alternative land uses (FRP 2005, Calder 2005, Hamilton and King 1983). In spite of the lack of clarity of land use-hydrological relations, payment systems or markets for watershed services are becoming popular. For example, New York City has been assisting farmers to change their land use, and in doing so has avoided the cost of constructing a massive water purification plant. Demand for secure delivery of the ‘commodity’ is consequently increasing and, with it, demand for better information about the ‘production process’ (Forest Trends, 2005; IIED, 2005).

3.2.2.1.4 Integrated soil and nutrient management (ISNM)

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	A	+1 to +5	G	Especially important in the tropics

Organic matter provides a source of soil nutrients, while improving soil structure for better aeration and water-holding capacity, increasing the benefits from irrigation and fertilizer amendments. Good soil structure is important for root growth and as a habitat for the soil organisms involved in nutrient cycling. The organic matter content of the world's agricultural soils is typically 50-65% of pre-cultivation levels:- 42-78 gigatonnes of carbon (Lal, 2004). Strategies to increase organic matter (carbon) in soil include: soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands. An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40kg ha^{-1} for wheat, 10 to 20kg ha^{-1} for maize, and 0.5 to 1kg ha^{-1} for cowpeas.

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
1, 3, 4,	B	+1 to +3	R	Mostly applied in dry areas temperate/sub-trop zone

In the United States, 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), >60 million hectares (Harington and Erenstein, 2005; Derpsch, 2005; Dumanski et al., 2006; Hobbs, 2006). Minimum tillage is a low-cost system. Landers et al. (2001) have demonstrated that no-till can reduce production costs by 15-20% by eliminating 4-8 tillage operations, giving fuel reductions of up to 75% (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, recent synthesis has suggested that adoption of no-till increases soil organic carbon about 450 kg C ha^{-1} yr^{-1}, but that 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 with environmental and forest conservation (Embrapa, 2006).

Fallows increase the carrying capacity of the land in a sustainable way.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	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, rebuilding a permanent plant cover of the soil surface, improvement of soil permeability by root activity and the return of organic matter to soil, protection against erosion by heavy tropical rain and wind, protection of the soil from direct radiation and warming, restoration of biodiversity, etc (Swift and Anderson, 1993; Swift et al., 1996; Buck et al., 1999). Natural fallows of this sort are no longer applicable in most places because population pressures on available land are too high, consequently shorter and more efficient fallows using leguminous shrubs and trees have be developed (Kwesiga et al., 1999). When soil fertility is severely depleted, some external mineral nutrients (phosphorus, calcium) or micronutrients may be needed to hasten plant growth and organic matter production.

Short-term improved fallows with nitrogen-fixing trees allow poor smallholder farmers trapped in poverty with severely depleted soil fertility to improve crop yields without the need to buy fertilizers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	A	+2 to +4	R	Especially important in Africa

Especially in Africa, easily-adopted, short-rotation, improved agroforestry fallows with nitrogen-fixing trees/shrubs can increase maize yield 3-4 fold on severely degraded soils (Kwesiga et al., 1999; Cooper et al., 1996). 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 poor maize farmers from the need to purchase nitrogen 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 reduce the Exploitable Yield Gap of maize. With income now starting to be generated from the sale of Agroforestry Tree Products (Degrande et al, 2006), it is possible that the Exploitable Yield Gap may be closed still further, if farmers invest in fertilizers.

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
1, 3, 4,	A	+2 to +4	G	Most situations: important in the tropics

The perennial habit of trees, shrubs and vines means that they reduce 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 (Figure 3.15). The deep and widespread roots both provide permanent physical support to the soil, and aid deep nutrient pumping, decreasing nutrient losses from leaching and erosion, etc. (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 numerous ecological niches in the soil for beneficial soil microflora and symbionts (Sprent, 1994; Mason and Wilson, 1994; Lapeyrie and Högberg, 1994). Additionally, leguminous trees improve nutrient inputs through symbiotic nitrogen fixation. These attributes of trees have been a dominant focus of agroforestry systems (Young, 1997)

Figure 3.15

The capacity of almost all plants to mobilize and exploit the soil for nutrients and water is enhanced by symbiotic associations between their roots and beneficial soil fungi (mycorrhizas).

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 4,	A	+2 to +4	G	Worldwide

Mycorrhizal associations play a key role in plant establishment and survival, especially in degraded environments. Consequently, the soil inoculum of these fungal species is an important component of the soil biodiversity with implications for sustainable function of natural ecosystems and agroecosystems (Waliyar et al., 2003). Some plants, mostly gymnosperms and some legumes, form specific associations as a root sheath (ectomycorrhizas) producing aerial fruiting bodies (toadstools) releasing spores into the air (Lapeyrie and Högberg, 1994), while others form specific associations with fungi invading the root tissues (endomycorrhizas) and producing subterranean fruiting bodies which release spores into the soil (Wilson and Mason, 1994). Many agricultural practices (land clearance, cultivation, application of fertilizers and fungicides) have negative impacts on mycorrhizal populations, affecting the species diversity, inoculum potential, fungal succession. Techniques to harness the appropriate fungi are critical for sustainable production.

3.2.2.1.5 Integrated crop and livestock systems

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	+1 to +3	L	Especially important in dry Africa

Smallholder livestock producers, especially nomadic herdsmen, follow broad production objectives that are driven more by their immediate smallholder needs than by the demands of a market (Ayalew et al., 2001). Nomadic herdsmen in many areas (eg. 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 integration of livestock with sedentary agriculture involving vegetables, cereals and tree crops within living fences/hedges has the potential to enhance production but may lead to social conflict (Leakey et al., 1999; Leakey, 2003) as nomads need access to wells and watering holes and dry season fodder. The effective integration of crop and livestock systems involves landuse planning for the provision of alternative sources of dry season fodder (eg. fodder banks), and continued access to watering holes and grazing lands. Participatory approaches to decision making are appropriate to avoid such conflicts between sedentary and nomadic herdsmen (Steppler and Nair, 1987; Bruce, 1998; UNCCD, 1998, 2004; Blay et al., 2004).

3.2.2.1.6 Mixed cropping

Cereal/legume systems can increase productivity and sustainability of intensive systems.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	+1 to +3	R	Especially important in Asia

Traditionally, the sustainability of intensive cereal-based systems in Asia was due to the presence of green manuring practices. However, increasing land prices and wage rates had made this option economically non-viable 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 which 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 improve cropping system productivity and sustainability in the long-term (Ali, 2005; Ali and Narciso, 1996). Mixed cropping also has the benefit of reducing pest infestations and diseases (ICIPE, 1970-1980s).

3.2.2.1.7 Agroforestry and ecoagriculture

Shifting cultivation systems have typically been replaced by less sustainable approaches to farming.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	A	-5 to 0	G	Smallholder agriculture

Throughout the tropics, shifting (swidden) agriculture was the traditional approach to farming with a forest fallow, representing a form of sequential agroforestry. It was sustainable until increasing population pressures resulted in increasingly shorter periods of fallow that deplete carbon stocks in soils and in biomass, and lower soil fertility (Palm *et al*., 2005a). 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. 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 that could restore soil fertility (Sanchez, 2002).

Farmers often protect trees producing traditionally-important products (food, medicines, etc.) on their farms when land is cleared for agriculture. Thus, shifting cultivation is sometimes replaced by more sedentary farming systems that are more sustainable.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	A	+2 to +4	G	Mainly smallholder agriculture

Throughout the tropics, trees of traditionally-important species have often been saved within new field systems created by shifting cultivation. These trees are a source of products which originally were gathered from the wild to meet the everyday 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., 2005a: 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)

After deforestation there is a positive relationship between human population growth and tree populations: More People: More Trees

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	B	+1 to +4	M-L	Mainly smallholder agriculture

In recent years it has been realized that the relationship between human population pressure and the population of trees in the landscape is not as simple as has been previously thought (Figure 3.16). It has long been recognized that deforestation is a typical response to human population growth, but now it is additionally recognized (Holmgren et al., 1994; Shepherd and Brown, 1998) that after the removal of forest, there is an increase in tree populations and farmers integrate trees into their farming systems (Michon and de Foresta, 1999; Place and Otsuka, 2000; Schreckenberg et al., 2002; Kindt et al, 2004). This counter intuitive relationship, found in east and west Africa (Holmgren et al., 1994; Kindt et al., 2004), the Sahel (Polgreen, 2007), and south east Asia (Michon and de Foresta, 1999), seems to be partly a response to labour 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, for example 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).

Figure 3.16

The search for alternatives to slash-and-burn led to the identification of sites where farmers have independently developed sedentary cultivation systems by planting tree crops together with food crops.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	A	0 to +5	R	Smallholder agriculture

Throughout the tropics there are numerous different examples (Palm *et al*., 2005). In Indonesia, when the food crops are abandoned after 2-3 years, a commercial fallow 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, which have been developed by farmers since the beginning of the 20th Century (Michon and de Foresta 1996). These commercial fallows are biologically diverse, provide a good source of income, sequester carbon and methane, protect soils and maintain soil fertility and generate social benefits from the land (see papers in Palm et al., 2005). The cocoa agroforests of Cameroon are somewhat similar. In this case, 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 deforestation, the intensification of agriculture, declining availability of land, changes in land ownership, etc.

Recent studies have given a better understanding of the biophysical and socio-economic factors affecting the emergence of Alternatives to Slash-and-Burn agriculture.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	+1 to +4	R	Mainly smallholder agriculture

One of the common and dominant outcomes from an international study 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., 2005). This will continue if tangible incentives that meet the needs and objectives of local people are not introduced to bring about a change; these will be very expensive if linked to the delivery of international public goods and services, like carbon storage, as suggested by Palm et al. (2005b). The current enthusiastic adoption of participatory domestication of trees providing both environmental services and marketable, traditional foods and medicines, suggests that a cheaper option may be to help farmers to help themselves (Tchoundjeu et al., 2006).

The shift from large-scale commercial plantations to small-scale, mixed cropping systems has benefited smallholder farmers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	+2 to +4	R	Mainly smallholder agriculture

Firstly, many cash crops formerly grown exclusively by estates have now emerged as smallholder crops, giving smallholder farmers' opportunities to: I) reduce their risks by ommercializ their cropping systems and income, and ii) expand their income generation, making smallholder farming more lucrative (mean net present values of $1471 being reported for intensive cocoa and mixed fruit tree farming systems in Cameroon – Vosti et al., 2005). Consequently, in Indonesia, many of the rural population are now smallholders growing 'jungle rubber' who fall somewhere between the two extremes of being: I) completely dependent on wage labour, and ii) completely self-sufficient (Vosti et al., 2005).

Twenty-five years of agroforestry research have developed techniques and strategies (eg. N-fixing short-term fallows and trees to restore agroecosystem services) to assist farmers to reverse soil nitrogen depletion without the application of fertilizers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 4	A	+2 to +4	M-L	Mainly smallholder agriculture

Leguminous trees fix atmospheric nitrogen through symbiotic associations with soil micro-organisms 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, like alley-cropping/hedgerow intercropping are of limited adoptability because of the labour demands, while others like short-term improved fallows are both effective and adoptable (Kwesiga et al., 1999; Franzel, 1999). Thus short-term improved fallows in Africa involving species such as *Sesbania sesban*, *Gliricidia sepium*, and *Tephrosia vogelii*, have been found to accumulate 100-200kg N ha^{-1} in 6-24 months and to raise maize yields from about 0.5t ha^{-1} to 4-6 t ha^{-1} (Cooper, et al., 1996). An external source of phosphorus in needed for active nitrogen fixation in many P-deficient tropical soils.

Short-term improved fallows with nitrogen-fixing trees allow poor smallholder farmers trapped in poverty with severely depleted soil fertility to improve crop yields without the need to buy fertilizers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 4	A	+2 to +4	M-L	Degraded soils

Especially in Africa, easily-adopted, short-rotation, improved agroforestry fallows with nitrogen-fixing trees/shrubs can increase maize yield 3-4 fold on severely degraded soils (Kwesiga et al., 1999; Cooper et al., 1996). 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 poor maize farmers from the need to purchase nitrogen 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 fallows reduce the Exploitable Yield Gap of maize.

Tree/crop interactions are now quite well understood.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	A	-2 to +3	M-L	Many situations

There are many different types of interaction between trees and crops in mixed farming systems, and there is much good evidence of the overall productivity (biomass) of agroforestry systems being greater than annual cropping systems, due to the capture of more light and water, or to improved soil fertility (Ong and Huxley, 1996). Land Equivalent Ratio is the most commonly used way to evaluate the effectiveness of mixed cropping systems. After 25 years of intensive study the complex physiological and ecological impacts of tree/crop interactions are well understood (Huxley; 1999; Ong and Huxley, 1996; van Noordwijk et al., 2004). 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 smallholders, recognize that the benefits are real.

Agroforestry riparian buffer strips are planted for bio-remediation of herbicide and nitrate pollution.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 4	B	+2 to +3	L	Temperate and tropical agriculture

The planting of trees in strategically important parts of the catchment to ommerci water capture and ommerci run-off is one of the generally ommercial ways of conserving water resources. In the corn belt of ommercial US, three years after placing agroforestry strips (trees planted in grass strips) on the contour in a corn/soybean rotation there was a 17% decrease in the loss of total phosphorus and a 37% decrease in the loss of nitrate N (Udawatta et al., 2004). Consequently, this 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 cost effective approaches to alleviating non-point sources of agricultural pollutants transported from crop lands.

Enhanced agroecological function is promoted by agroforestry.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	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 precise 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 (Gliessman, 1998; Altieri 1989) and are based on the concept of commercial natural ecosystems (Ewel, 1999). Through the integration of trees in farming systems (the planned and commercially important biodiversity) 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 (the unplanned biodiversity) (Ewel, 1999; Leakey, 1999; Schroth et al., 2004). This 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, conferring some control of pests and diseases, weeds, etc (Collins and Qualset, 1999). These functions of agroforestry make it appropriate for the rehabilitation of degraded farmland.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	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: (i) direct near-term C storage (decades to centuries) in trees and soils, and, (ii) 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 provide goods and services which potentially offset 5–20 ha of deforestation. On a global scale, agroforestry systems could potentially be established on 585–1275×10^6 ha of technically suitable land, and these systems could store 12–228 (median 95) Mg 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 also ‘Carbon sequestration and the impacts of climate change’ in subchapter 3.2.2.2.4

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	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, especially food, medicines, building materials, artifacts, etc (Falconer, 1990, Abbiw, 1990; Villachica, 1996; de Beer and McDermott, 1996; Cunningham, 2001). NTFPs are still of great importance to communities worldwide (Kusters and Belcher, 2004; Sunderland and Ndoye, 2004; Alexiades and Shanley, 2004) and their enhanced marketing and wider use and has potential to support the livelihoods of forest communities and increase the commercial of natural forests, so strengthening initiatives to promote the conservation of forests and woodlands, especially in the tropics. NTFPs are rich in major nutrients, minor nutrients, vitamins and minerals (Leakey, 1999) and have the potential to provide future products for the benefit of mankind. However, such future developments 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 increasing being grown in smallholder farming systems, and have become recognized as farm produce (Agroforestry Tree Products – AFTPs).

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	A	+1 to +3	R	Relevant worldwide

Smallholder farming systems commonly include both exotic and native tree species (Schreckenberg et al., 2002, 2006; Degrande et al., 2006; Shackleton et al., 2002; Kindt et al., 2004) producing a wide range of different wood and non-wood products. Such products include traditional foods and medicines, gums, fibres, 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). 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 smallholder farmers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	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 and other day-to-day products (Okafor, 1980, Smartt and Haq, 1997, Guarino, 1997; Schippers and Budd, 1997; Sunderland et al., 1999; Schippers, 2000), 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), smallholder farmers recognize the importance of producing and trading these traditional food species for domestic and wider use. These programmes are starting to show livelihood impacts at the household level (Schreckenberg et al., 2002; Shackleton et al., in press; Degrande et al., 2006), as well as being important for food and nutritional security. Many of these new crops also important as sources of feed for livestock (Bonkoungou et al., 1998), and potential new markets, eg. vegetable oils (Kapseu et al., 2002) and pharmaceuticals/nutriceuticals (Mander et al., 1996; Mander 1998). Farmers also appreciate that the integration of these species in the farming system to meet specific income needs (eg. school fees and uniforms – Schreckenberg et al., 2002) and provide risk aversion, for example buffering the effects of price fluctuation in cocoa and other commodity crops (Gockowski and Dury, 1999). This emerging market orientation needs to be developed carefully as it is potentially in conflict with community-oriented values and traditions. A series of “Winners and Losers” projects on the ommercialization of NTFPs (now Agroforestry Tree Products – AFTPs) have examined these options (e.g. Shackleton et al., in press; Leakey et al., 2005; Marshall et al., 2006). These systems target the restoration of natural capital and the well-being the resource-poor farmer and combine the ecological benefits with those specifically aimed at cash generation from AFTP (Leakey et al., 2005). The integration of domesticated indigenous fruit and nut trees into cocoa agroforests would further improve a land use system which is already one of the most profitable and biologically diverse (Figure 3.17)

Figure 3.17

Low-tech clonal approaches to agroforestry are using participatory domestication techniques to develop cultivars of new tree crops.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	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 fruits and nuts traits (Atangana et al., 2001, 2002; Anegbeh et al., 2003, 2005; Waruhiu 2004; Leakey et al., 2005a/b). Using participatory approaches (Leakey et al., 2003), the implementation of these techniques is being successfully achieved by smallholder farmers (Tchoundjeu et al., 2006) (Figure 3.18).

Figure 3.18

Agroforestry trees meet the needs of smallholder farmers and have the capacity to produce new agricultural commodities and generate new industries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3	B	+2 to +3	L	Mainly smallholder agriculture

In many countries there are deficits of edible oils and livestock feeds and fodder (FAO 2003), but many indigenous tree species are an under-utilized resource of these products. For example, in West Africa, edible oils are produced by *Allanblackia* spp. (Tchoundjeu et al., 2006), *Irvingia gabonensis* (Leakey, 1999), *Dacryodes edulis* (Kapseu et al., 2002), *Vitellaria paradoxa* (Boffa et al., 1996) and many other agroforestry species (Leakey, 1999). Unilevers are 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. For example, *Calliandra calothyrsus* is used in Kenya and is excellent for dairy cattle (3 kg of *C. calothyrsus* fodder = 1kg of concentrate giving a yield of >10kg milk d^{-1} with a buttermilk content of 4.5%), *Pterocarpus erinaceus* and *Gliricidia sepium* are grown in fodder banks for cattle and goats and traded in the Sahel (ICRAF, 1996; 1997), while *Chamaecytisus proliferus* hedges are browsed by cattle in Western Australia (Wiley, 2000). Opportunities for cattle cake exist from by-products of species producing edible fruits and nuts (eg. *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).

Agroforestry has developed strategies and techniques of special relevance to Africa for the rehabilitation of degraded agroecosystems and the reduction of poverty.

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, 2001a/b) At the community level, agroforestry can have positive impacts on food security, the livelihoods of smallholder farmers and the reversal of environmental degradation by: I) providing simple biological approaches to soil fertility management (Young, 1997; Sanchez, 2002), ii) generating income from tree crops (Degrande et al., 2006), iii) minimizing risk by diversifying farming systems (Leakey, 1999) and iv) restoring agroecosystem services (Sanchez and Leakey, 1997). Consequently, agroforestry has been recognized as an especially appropriate alternative development strategy for Africa (Leakey, 2001 a/b), where the Green Revolution has had only modest success (Evenson and Gollin, 2003).

Ecoagriculture is an approach to land use that seeks to simultaneously achieve production and wildlife conservation through sustainable land use.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	0 to +4	G	Worldwide applicability

Ecoagriculture has much in common with agroforestry, but the motive for the Ecoagriculture initiative is the needs to secure land as protected areas for wildlife habitat ecognizing that they are the same areas that may need to be cleared for future agriculture (McNeely and Scherr, 2003; Buck et al., 1999, 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 is a scientific basis for optimism and that there are many cases of “biodiversity-friendly” agriculture (Buck et al., 2004). Nevertheless, economic considerations involving issues of valuation and payment for ecosystems services, as well as building a bridge between the different mindsets of agriculturalists and conservation scientists will be a major challenge.

3.2.2.1.8 Watershed Management

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	A	0 to +3	M-L	Wide applicability

In contrast to the situations where water schemes are not managed sustainably, there are traditional user-managed, water catchment and management projects in many parts of the world (eg. in southern India or of the mountainous regions of the Andes, Nepal or upland south east Asia), which are in harmony with the environment. They do not severely alter the hydrological cycle or use more water than what is available at sustainable levels (Molle, 2003; Ruf, 2001), in contrast with some modern schemes, which do not recognize limitations of available fresh water resources and proceed to create severe problems (www.unep.org, undated): Syr and Amu Dar’ya rivers have shrunk to less than half their original size, due to intensive irrigation of cotton and rice in the former Soviet Union, between 1957-2001. These examples illustrate the desirability of working with local people and their traditions, rather than against them.

The Lake Victoria Basin project is an example of an integrated watershed approach to assessing environmental degradation and its biophysical and socio-economic impacts.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3 4, 5	B	0 to +2	N	Widespread applicability

Lake Victoria is the world's second largest lake (68,000km^2) and located in an agricultural area with high population density (28 million people on 116,000km^2 of farm land). Detailed studies have determined the magnitude of the land and lake degradation problems and associated these with river sediment loads, soil types, nutrient depletion, farming practices, agricultural extension, socio-economic needs of the population and biophysical factors at scales up to 100km^2, using participatory monitoring and evaluation, spectral reflectance and remote sensing, and agroforestry and livestock exclusion trials (Swallow et al, 2002; www.fao.org/WAIRDOCS/TAC/Y4953).

3.2.2.1.9 Organic systems and bio-intensive agriculture

The principles of organic agriculture encompass production practices that aim to promote environmental quality and ecosystem functionality.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	A,F,D,E	+1 to +4	G	Worldwide

Organic agriculture is based on minimizing the use of synthetic inputs for soil fertility and pest management. From a consumer viewpoint, organic agriculture is valuable for avoiding the perceived health and environmental risks posed by pesticide residues, growth-stimulating substances, genetically-modified organisms and livestock diseases. The other main driver of growth of the industry (FAO/WHO, 1999) stems from the putative environmental benefits associated with organic production practices. Organic agriculture includes not only certified organic production systems. Non-certified farms and products that comply with the principles and practices of organic agriculture are also included. The extent of non-certified systems, particularly in developing countries, is difficult to estimate. (El-Hage Scialabba and Hattam, 2002).

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
2, 4, 5, 6	A	+1 to +3	G	Wide applicability

There has been a steady rise in the area under organic agriculture (Figure 3.19). 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 (United Nations, 2006). 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 (United Nations, 2006). The harmonization of organic standards has become 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 also through CODEX guidelines. The Codex guidelines concern the production process and provide consumer and producer protection from misleading claims and guide governments in setting organic standards (FAO/WHO 1999, FAO, 2003; El-Hage Scialabba 2005; United Nations 2006).

Figure 3.19

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 4, 5	A	+1 to +4	G	Worldwide applicability

Globally organic production covers 31 million ha on more than 600,000 farms in approximately 120 countries (Figure 3.20). Organic production is also 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 hectares). Latin America has the greatest total number of organic farms (Willer et al 2006 cited in http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3). By region, most of the world’s certified organic land is in Australia / Oceania (39%), Europe (21%), Latin America (20%), Asia (13%). In Switzerland, more than 10% of agricultural land is managed organically. Large areas of the worlds agriculture land, particularly in developing countries and some former Russian States, are ‘organic’ by default (ie. non-certified), as farmers cannot afford to purchase fertilizers and pesticides (Willer et al, 2006). The extent of such non-market organic agriculture is difficult to quantify but some attempts have been made. Anobah (2000) estimates that >33% of West African agricultural produce is produced organically. Cuba uses organic agriculture to produce 65% of their rice, 46% of fresh vegetables, 38% of non-citrus fruit, 13% of roots, tubers and plantains and 6% of the eggs which has been supported by substantial government investments in research and extension (Murphy, 2000).

Figure 3.20

While organic agriculture does not typically attain the productivity levels achievable with conventional agricultural practices, in many cases it offers an economically-competitive alternative

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	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; Eltun et al., 2002). While yields may be 10-30% lower from organic farms, particularly after conversion from conventional agriculture practices, an analysis of European farm economics concluded that profits on organic farms in Europe are, on average, comparable to those on conventional farms (Hohenheim, 2000 cited in http://www.fao.org/ORGANICAG/frame6-e.htm). However, it can take several years to restore biological activity (e.g. growth of soil biota, improved nitrogen fixation and establishment of natural pest predators), and as a result pest and fertility problems are common during transitions phases 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 such as indigenous nutrient supplying capacity of the soil (FAO, 1999h cited in FAO 2003). However when low-input, traditional systems convert to organic agriculture yields typically do not fall and often increase. (ETC/KIOF, 1998 cited in FAO 2001; http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 4	A	-3 - +5	G	Widespread

While intensive use of synthetic agro-chemicals for pest management is a foundation of modern agriculture, their use has also been linked to a host of negative impacts including ground and surface water contamination (USGS, 1998; Barbash et al., 1999), 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, the lower efficacy of many organic pest control methods is partly responsible for the yield penalty associated with many organic systems.

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
2, 4	A	-3 - +5	G	Widespread

Adequate stocks of soil organic matter are vital for maintaining soil quality. Among many important functions, soil organic matter is an important source of macro and micro-nutrients 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. Husain, 2004; 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). Moreover, in very high population pressure or degraded environments some of the most common organic resources available to farmers (e.g. cereal stovers) are of poor quality, having low nutrient concentrations and macro-nutrient ratios that are not well matched to 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 as a complement to bridge deficits between crop needs and indigenous supplies, but such approaches are not commonly practiced in developing countries (e.g. http://www.knowledgebank.irri.org/ssnm/)

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

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

Since organic agriculture is more clearly defined by what it prohibits (e.g. synthetics) rather than what it demands, the environmental benefits that accrue from organic production are somewhat difficult to generalize. The absence of synthetic pesticides provides a clear environmental advantage that unites all organic production systems. Some evidence also suggests that above and below-ground biodiversity is typically higher in organic systems (Bengtsson et al., 2005; Mäder et al., 2005), but neutral outcomes are also reported from long-term experiments (e.g. Franke-Snyder et al., 2001) and species richness sometimes increases among some organisms groups while others are unaffected (Bengtsson et al., 2005). Biodiversity impacts in 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 suggest reduced environmental losses of nutrients like of nitrate nitrogen 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, these energy savings must be balanced against productivity reductions (Dalgaard et al., 2001). For organic systems with substantially lower yields than conventional alternatives, enterprise energy efficiency (energy output per unit energy input) can actually be lower than the efficiency of conventional systems (Loges et al., 2006).

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

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

Although 1-2% of global food sales are small, there are some products in which organic production is very substantial. For example, in Germany, Organic ingredients in baby foods represent 80-90% of the market, while organic milk products represent 10% within the 3-4% of total sales represented by organic products , In the USA, organic coffee accounts for 5% of the market although it is only 0.2% worldwide (Vieira, 2001 cited in http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3). The total market value of organic products worldwide, reached US$27.8 billion in 2004. There has been annual market growth of 20-30%, much higher than growth in the overall food production sector of 4-5% per year (*ftp://ftp.fao.org/paia/organicag/2005_12_doc04.pdf*).

Organic markets are mostly in developed countries but developing countries are emerging as new organic markets and have a comparative advantage in meeting demand for many organic foods.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	B	+1 to +2	G	Worldwide applicability

Although the highest market growth for organic produce is in North America, **t**he highest reported domestic market growth, estimated to be up to 30%, is in China and an organic boom seems to be taking place in Indonesia. The range of marketing approaches is diverse and includes organic bazaars, small retail shops, supermarkets, multi-level direct selling schemes, community supported agriculture and internet marketing (Willer et al, 2006; IFOAM 2006; (FAO/ITC/CTA 2001 http://www.fao.org/ORGANICAG/doc/y1669e00.htm, The low external input production systems found in many developing countries are more easily converted to certified organic systems than high external intensive production systems found in most developed countries.. Organic tropical and sub-tropical products such as coffee, tea, cocoa, spices, sugar cane and tropical fruits offer a particular opportunity. Traditional low external input systems generally do not use agro-chemicals and may already maintain soil fertility in sustainable ways. In such situations the transition to organic agriculture may be easier, require less investment and risk than for farmers in countries with highly intensive agriculture. The higher labour requirements of organic farming also offers a comparative advantage to developing countries, where labour costs are relatively low (Hartwig de Haen 1999, http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3).

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
6	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 already be difficult due to limited and unreliable infrastructure and a lack of skilled labour. Evidence suggests that the current price premium for organic produce will decline in the long term as supply rises to catch up with demand and also as larger corporate producers and retailers enter the market. A lower price premium may make organic agriculture uneconomic for many small producers in developing countries with poor rural infrastructure and services (Hartwig de Haenl, 1999). However, these constraints provide an opportunity for developed countries to assist developing countries to expand their 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

3, 6	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 as well as 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, set up partnership with organic companies, or have their own organic lines. Mergers and acquisitions of organic brands and companies impact production, processing, certification and distribution pathways: eg 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. Domination of the organic market by big companies controls market access, and results in price regulation that minimizes economic returns to farmers. This trend is undermining one of the central pillars of organic agriculture – that it shold provide a better return to farmers and help pay for the costs of sustainable production. This concentration of of the industry is leading to pressure for the erositio of organic standards. For example in the United States, the food industry pressure on the Government is threatening national organic standards (with proposed modifications on synthetic substances, animal feed and commercial availability of organic ingredients without public review) (El-Hage Scialabba, 2005). This is leading to a market economy, which is anything but transparent.

Reversing the loop of globalization by reducing supermarket control of supply of organic produce is being attempted through the localization of marketing.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 6	A	+1 to +3	R	Small-scale producers and traders

Some successful attempts have been made to empower smallholders and to promote localized food systems by supporting community-based, short food supply chains in domestic markets. Strategies include organic farmers markets, box home delivery and community supported agriculture. Generally these initiatives are small in scale but seen in total and as a global trend in developed and developing countries their impact is significant. One example of larger scale success is a farm in Denmark that raised its nationwide delivery of organic boxes to 22,000 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. farmers' associations, inspectors, accreditors, traders, retailers, consumers) and the development of Organic Farmers-Field-Schools to promote location-specific research and knowledge sharing (El-Hage Scialabba, 2005).

3.2.2.2 Managing for ecosystem services and public goods

3.2.2.2.1 Provision of ecological services

The 'ecological footprint' of people from different nations and cultures is very different, being largest in the developed world (about 10ha) and least in poor developing countries (<2.5ha).

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

4	B	-5 to +5	G	General principle

The ‘ecological footprint’ is an indicator of the environmental impact on the land and/or sea, attributable to a person. It assesses the stocks of natural capital (ecosystem resources) that are required for a particular population, product, activity or service in support of the economy. The planet has about 10 billion ha of productive land. The global population is 6 billion and rising, so at present there is about 1.7 ha per person, falling to 1.0 ha if there are 9 billion people by 2050 (Simmons, 2001). Globally, the current ecological footprint of a human being is untenable for the future. To improve this situation and raise the standards of living, especially in the developing countries, significant adjustments in terms of trade and regional self-reliance will be needed, together with policies to stimulate an increase in the material and energy efficiency of economic activity (Rees, 1996; Chambers et al., 2001; Lenzen and Murray, 2001; Lewan and Simmons, 2001). To achieve equity, the per capita ‘footprint’ should be about 1ha by 2050.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	-3 to +4	G	General principle

Monocultural farming systems are characterized by low biological diversity and dependence on external inputs (pesticides, fertilizers, etc) to replace natural systems of nutrient cycling, pest and disease control, etc. A number of other approaches to diversified agriculture (ecoagriculture, agroforestry, organic agriculture, conservation agriculture, etc.) seek to ensure agricultural productivity by more natural processes (described above in Subchapter 3.2.2.1).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	A	-3 to +3	G	Wide aplicaility

Eighty five million tonnes of nitrogen were used in 2000 to enhance soil fertility. These human activities impact on the natural nitrogen cycle in the following ways: 1) doubled the rate of nitrogen input into the terrestrial nitrogen cycle, with these rates still increasing; 2) increased concentrations of the potent greenhouse gas N_2O globally, and increased concentrations of other oxides of nitrogen that drive the formation of photochemical smog over large regions of Earth; 3) caused losses of soil nutrients, such as calcium and potassium, that are essential for the long-term maintenance of soil fertility; 4) contributed substantially to the acidification of soils, streams, and lakes in several regions; and 5) greatly increased the transfer of nitrogen through rivers to estuaries and coastal oceans. In addition, human alterations of the nitrogen cycle have: 6) increased the quantity of organic carbon stored within terrestrial ecosystems; 7) accelerated losses of biological diversity, especially losses of plants adapted to efficient use of nitrogen, and losses of the animals and microorganisms that depend on them; and 8) caused changes in the composition and functioning of estuarine and near-shore ecosystems, and contributed to long-term declines in coastal marine fisheries. (Vitousek et al., 1997).

Estuarine habitats are important nursery grounds in the production of commercially important marine fishes, but are subject to detrimental agricultural, urban and industrial developments.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4	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 emphasised the importance of the connectivity between estuarine 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 degradation and other detrimental human impacts, information about the behaviour and resource use of juvenile fishes is crucial for future fisheries management and conservation (Leakey, 2006).

3.2.2.2.2 Water quality and quantity

Water quality can be improved by planting riparian buffer strips

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 4	B	+2 to +3	L	Temperate and tropical agriculture

Riparian buffer strips made by planting grasses and/or trees have been widely used in the USA for the reduction of water pollution by silt, herbicides and fertilizers (Louette, 2000; Schultz et al., 1995, 2000; Lin et al., 2003, 2005). See also ‘Agroforestry buffer strips’ in Subchapter 3.2.2.1.7

Water scarcity affects many parts of the world today and is getting worse.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	A	-1 to -5	G	Especially severe in dry tropics

At present, 1 billion people lack clean drinking water and 2.4 billion lack basic sanitation (Turnbull, 2006), and this scarcity impacts adversely on agriculture. Eighty countries, with 40% of the world population, are facing water scarcities (UNWCED, 1987) The causes of water scarcity include: 1) Over extraction of a water for agriculture from rivers, ground water resources, aquifers and wetlands, 2) Pollution of freshwater resources (about 95% of the world's cities still dump raw sewage into rivers), and 3) Drought resulting from climate change. The severity of water scarcity is felt more acutely today than in the past due to increased consumption for domestic and agricultural use, urbanisation and industrialization. Since 1900, there has been a six-fold increase in water use for only a two-fold increase in population size. This reflects greater water usage associated with rising standards of living, more intensive agriculture, including increased use of irrigation and salinity problems (now 45 million ha worldwide). India provides an illustration of the overuse of ground water for agriculture. In the last twenty years the area of land irrigated by groundwater in India has more than doubled to

27 million ha, whereas the area of surface water irrigated land has increased by little more than 25% to 21 million ha.

During the twentieth century, governments dramatically expanded their roles in water management.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	A	+1 to +3	G	Worldwide

In response to water scarcity, decisions about the creation of irrigation schemes have often given inadequate consideration to their environmental impacts (Acreman, 1998) and led to reduced flows to wetlands downstream (Hollis et al., 1995). The economic impacts of such schemes often fail to recognize that the water can be many times more valuable downstream to support fisheries, agriculture, etc. (Barbier et al., 1991). 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, and waste emission. The rules and procedures of such projects play a major role in determining who received water. Agriculture is by far the largest sector of water use in most countries, but its share of freshwater resource use decreases with increased industrialization (World Resources Institute, 1997 in: de Sherbinin and Dompka, 1998, UN and WMO, 1997). Agricultural users are the most likely to have some system of traditional water rights, which may be overlooked by the agency. Communities of water users, therefore, face numerous challenges in gaining equitable and sustainable access to, and allocations of, water (Bruns and Meinzen-Dick, 2000; Meinzen-Dick and Pradhan, 2002). Water User Associations are a common way of managing water delivery (Abernethy, 2003). The equitable distribution of irrigation water, for example, is achieved by allowing the same duration of water delivery to each irrigated hectare, or the same quantity of water to each household (Shlager, 2003).

Water conservation techniques allow more efficient use of water resources.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	A	+1 to +3	G	Wide applicability, important in dry areas

Water conservation techniques maximize capture, retention and wise use of water. Drip irrigation minimizes negative impacts (e.g. salinization) by reducing evaporation losses). The conservation (water quantity and quality), efficiency and equity of water use are also important considerations in decision making about water resource use (Turner et al., 2004). Promising approaches to better water management include: gains in water productivity, better management of rainfed agriculture (60% of crops), stakeholder management schemes and reduced evaporation. In China, biological modifications, environmental control, technological management (Deng et al., 2004), and participatory integrated watershed management (German et al., 2006) have resulted in more efficient use of water resources.

Water allocation for agriculture and future food security is emerging as the key social constraint to meeting the needs of water users.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	B	+1 to +3	R	Wide applicability

Social reforms to improve the equity of water allocation include providing secure water rights for users and reducing or eliminating water subsidies. Farmers have also proven to be willing and able to make substantial contributions to the construction and improvement of irrigation systems, when the projected benefits in terms of water allocation outweigh the costs. Their contributions create a stronger sense of ownership, leading to better subsequent operations and maintenance (Burns and Ambler, 1992). The better performance of farmer managed irrigation schemes was confirmed in a worldwide study of 40 irrigation schemes (Tang, 1992), and a study of over 100 irrigation systems in Nepal (Lam, 1998).

Structurally complex landuse systems can enhance hydrological processes and provide some relief from water scarcity.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B, E	+1 to +2	R	Large land masses

On a regional scale, the surface roughness of the vegetation, its canopy water-holding capacity and its ability to release moisture back to the atmosphere affect 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 run-off, groundwater and a reduction of evaporation and transpiration from the canopy (Salati and Vose, 1984; Shuttleworth, 1988; Rowntree, 1988). Thus the maintenance of perennial vegetation has positive effects that enhance hydrological processes (Meher-Homji, 1988; Foley, et al., 2003) affecting the amount of moisture that can be advected downwind to fall as rain somewhere else (Figure 3.21). Agroforestry systems can probably mimic these hydrological functions of natural forests (Leakey, 1996).

Figure 3.21

Evidence relating farm size to productivity and efficiency is weak.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	C	-4 to +4	G	Variable

While some regionally specific research has concluded that productivity and efficiency are positively related to farm size (Yee, Ahearn, and Huffman 2004, Hazarika and Alwang. 2003), international evidence indicates that large-scale mechanized farms are generally inefficient compared to smaller family farms (Van Zyl, 1996). However, the lack of clear evidence indicating any relationship between farm size and productivity and efficiency probably indicates that there are numerous other confounding factors involved, 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). Good management, on large and small 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 poor small-scale farmers reduce inputs, diversify, and seek risk aversion. Interestingly, is often among the latter group that some of the best examples of sustainable agriculture are found, especially in the tropics (Palm et al., 2005; Leakey, 2005b).

3.2.2.2.3 Conserving biodiversity (in situ, ex situ) – **To be completed**

***Ex situ* genetic conservation techniques have been improved to allow seeds of even some of the most recalcitrant species to be stored long-term.**

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

This has raised policy issues about germplasm ownership which have also been addressed. – to be completed

- **Species domesticated for a long time also need conservation of genetic diversity**

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

- **Germplasm storage (*In vitro* v *Ex vitro*)**

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

- **Genebanks**

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

- **Cryopreservation.**

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

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

Agriculture has contributed to the greenhouse warming potential of the atmosphere and directly to climate change.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	-1 to -3	G	Causes differ in temperate and tropic zones

Agriculture has contributed to climate change and the radiative forcing potential of the atmosphere (Greenhouse Warming Potential) in the following different ways (Norse, 2003; Bruinsma, 2003; USEPA, 2006): heat emission from burnings of forests and pastureland (Fearnside, 2000); greater sensible heat fluxes (Foley et al., 2003), infrared radiation from bare soil (CIRA, 2005; LSC, 2006) and reduced evaporation from soils without vegetative cover; a decrease in surface albedo (i.e. sunlight reflectance) when plant residues are burned (Randerson et al., 2006); carbon dioxide emissions from the energy-intensive process to required to produce agricultural amendment like nitrogen fertilizers from the Haber-Bosch process (USEPA, 2006); soil organic matter oxidation promoted by tillage (Reicosky, 1997); methane emissions from ruminant livestock (Johnson and Johnson, 1995) and wetland rice cultivation (Minami and Neue, 1994); and nitrous oxide emissions (Smith et al., 1997) from poorly-drained soils, especially under conditions where N fertilizers are over-applied. In aggregate, agriculture is responsible for approximately 15% of anthropogenic CO_2 emissions, 49% of methane (CH_4) emissions and 66% of N_2O (Bruinsma, 2003; IPCC, 1995). Methane emissions come largely from wetland/irrigated rice, and emissions from livestock.

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
1, 3, 4, 5	A	-3 to +3	G	Especially important in the tropics

In addition to being a source of greenhouse gas emissions, certain agricultural practices have also been 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 (reference), (ii) maximizing the efficiency of nitrogen 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 photo-chemically active with OH radicals; OH radicals remove atmospheric CH_4 (Crutzen and Zimmerman, 1991; Tuinder, 2002; Chatfield, 2006).

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 of the previous predictions.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 4, 5	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). These experiments have shown that 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). This casts 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), (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
1, 4, 5	B	-3 to +3	R	Variation between crop species

Wheat, rice and soybean are C_3 crops in which photosynthesis is directly stimulated by elevated CO_2 (Long et al., 2004). When grown at 550 ppm CO_2 (the concentration expected for 2050), yields increased by 13, 9 and 19% for wheat, rice and soybean, respectively (Long *et al.,* 2006). In contrast, C_4 photosynthesis in maize and sorghum is not directly stimulated by elevated CO_2. Therefore, these crops do not show an increase in yield when grown with adequate water supply in the field at elevated CO_2 (Leakey et al., 2004, 2006; Ottman et al., 2001; Wall et al., 2001). However, at elevated CO_2, there is an amelioration of drought stress due to reduced water use. Therefore, yields of maize, sorghum and similar crops might benefit from elevated CO_2 under drought stress.

Soil-based carbon sequestration (CS) provides a significant, but finite sink for atmospheric CO_2.

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

In recognition that social and economic factors ultimately govern the sustained adopted 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). Increased soil organic matter is positively associated with attributes that are favorable to crop growth like soil tilth, water holding capacity, and fertility (e.g. Lal et al, 1997). Although some 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 landuse 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 best viewed as an interim measure for sequestering atmospheric CO_2. In the short-term, some estimates have suggested that increased carbon sequestration in soils has the potential to store 0.4 to 1.2 gigatons of carbon per year (5 to 15% of the global carbon emissions from fossil fuel) (Lal, 2004). The United States has 132 million ha of cropland. If all of this was converted to no-till, CS rates of 0.059 petagrams yr^{-1} are attainable in the near-term and would compensate for slightly less than 4% of the annual CO_2 emissions from burning fossil fuels in the US (Jackson and Schlesinger, 2004).

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
1, 3, 4, 5	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. Duxbury (2005) notes that no-till maize systems are associated with comparatively large emissions of N_2O (see Smith and Conen, 2004). Over a 100-yr timeframe, N_2O is 310 times more potent in terms of GWP than CO_2 (Majumdar, 2003) and the higher N_2O emissions from no-till systems may negate most of the apparent benefits from increased rates of carbon sequestration. On the other hand, soil structural regeneration in no-till systems over time may result in a fewer N_2O emissions in the long-term. 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, Izauralde et al. (1998) estimated that 1.436 moles of CO_2-C were released per mole of N applied as fertilizer. At this carbon efficiency, 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).

Agroecosystems involving tree-based carbon sequestration reduce greenhouse gas emissions.

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

Early assessments of national and global terrestrial CO_2 sinks reveal two primary benefits of agroforestry systems: (i) direct near-term C storage (decades to centuries) in trees and soils, and, (ii) 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 of technically suitable land, and these systems could store 12–228 (median 95) Mg C ha^{-1} under current climate and soil conditions (Dixon, 1995). In the tropics, estimates suggest that within 20-25 years the rehabilitation of degraded farming systems through the development of tree-based farming systems results in above-ground carbon sequestration from 5t C ha^{-1} for coffee to 60t C ha^{-1} for complex agroforestry systems (Palm et al., 2005b). Below-ground carbon sequestration is generally lower, with an upper limit of about 1.3t C ha^{-1} yr^{-1}. However, recent evidence suggests that agroforestry systems with nitrogen-fixing tree species, which are of particular importance in degraded landscapes, are 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 reduced stream flow and some soil modification (Jackson et al., 2005). See also role of ‘Agroforestry in the reduction of anthropogenic trace gas emissions’ in Subchapter 3.2.2.1.7

Climate change is affecting crop-pest relations.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	0 to -3	G	Worldwide

Climate change has been found to favour new pest introductions to habitat change (McLaughlin et al., 2002; Hill et al., 2001), to changes in pest/predator/parasite population dynamics (Prior and Halstead, 2006; Menendez et al., 2006; UCSUSA, 2007), through 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. Such changes affect the ecology of the pests, their evolution and virulence of different organisms. Similarly, population dynamics of the insect vectors of disease, and the ability of parasitoids to regulate pest populations, can change (FAO, 2005), as found in 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 (FAO, 2005; Rosenzweig, 2001). Modelling is being used to predict some of these changes (Oberhauser and Townsend Peterson, 2003) and to predict the consequence of some of the above changes. This is aimed at the development of improved plant protection measures, such as early warning and rapid response to potential quarantine pests. Better information exchange, is also required to counteract global warming.

However, the impacts of climate change are not uni-directional and there can be benefits (Examples?).

Livestock holdings are sensitive to climate change, especially drought.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	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). Firstly, animals are very sensitive to heat stress; secondly they have to have a reliable resource of drinking water, and thirdly, pasture is also very sensitive to drought (Zao et al., 2005). In addition, infectious and vector-borne animal diseases have become increasingly important worldwide and disease emergencies are occurring with increasing frequency (FAO, 2002). These problems are thought to be exacerbated by climate change through impacts of climate on the ecology of the vectors and hosts, and secondly because hunger, thirst and heat-stress, increase susceptibility to diseases. The poor do not have the capacity to take appropriate action to minimize these risks.

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
1, 3, 4, 5	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 pest and disease (FAO, 2005; Stireman et al., 2004). Established pests may become more prevalent due to favourable growing conditions that include higher winter temperatures and rainfall. For example, the last decade in UK has seen warmer than average annual temperatures and species have become established that were only seen rarely before, such as the vine weevil and red mites (*Tetranichus urticae*), with potentially damaging economic consequences (Prior and Halstead, 2006). Warmer conditions may increase the pest developmental rates and 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 which will negatively impact crop yields. Climate variability may also reduce the effectiveness of parasitoids (Stireman et al., 2004) (This may also impact insect vectors of plant diseases, such as the scale insects that transmit beech bark cankering (*Nectria* spp.) to beech trees in Northeast USA. Their effectives may increase with warmer weather, producing more severe infection (FAO, 2005). On the other hand, climate change may also negatively impact pests; it may increase pest mortality rates due to lower temperatures during winter (examples?)

Climate change also has impacts on human and livestock health, linked to changes in agricultural and land use practices.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	Not yet clear	G	Mainly tropical

Impacts of climate change on farming practices and wetland management, can affect the distribution and range of insect vectors of human and livestock diseases, species like mosquitos (malaria, encephalitis, dengue), ticks (tick typhus, lyme disease), tsetse fly (sleeping sickness). Any information on the agricultural linkages?

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C		G	Wide applicability

Crop yields are expected to decline in most tropical and sub-tropical regions as rainfall and temperature patterns change with a changing climate (IPCC, 2001). LULUCF activities are ‘carbon sinks’ as they capture and store carbon out of the atmosphere through the processes of 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 (Michon, 2004).

3.2.2.2.5 Energy to and from agricultural systems - efficiency and bioenergy

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
4	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 (Figure 3.22). 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 (Figure 3.23), such as the efficient use of solid, liquid or gaseous biomass for the production of heat, electricity or transport fuels – which is characterized by a high versatility, efficiency and relatively low levels of pollution – accounts for 2.3% of the world's primary share of energy (Bailis, et al., 2005; FAO, 2000; IEA, 2002; Kartha, et al., 2005).

Figure 3.22

Figure 3.23

Traditional bioenergy is associated with considerable social, environmental and economic costs and while it appears to be a consequence of poverty it is also an inhibitor to social and economic development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 4, 5	A	-3 to +2	G	Especially in the tropics

The energy efficiency of traditional biomass fuels (eg. woodfuels in traditional cooking stoves) is very 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 of biomass is also responsible for polluting fumes in the homestead leading to 2.5 million premature deaths per year (WHO, 2002). Collecting fuelwood is also time-consuming, reducing the time that women and children can devote to farming and education each day (Bailis, et al., 2005; Goldemberg and Coelho, 2004; IEA, 2002; Karekezi, et al., 2004; UNDP, 2000; World Bank, 2004).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	0 to +3	G	Wide applicability

Modern biofuels, such as bioethanol and biodiesel contributed only about 1% of the total road transport fuel demand worldwide in 2005 (IEA, 2006c). The main products are: (i) Ethanol, which 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 United States (16,230 million liters) in 2005, out of a world production of over 40,100 million liters (Renewable Fuels Association, 2005; Worldwatch Institute, 2006). By 2000, sugar cane derived ethanol met 25% of Brazil's gasoline demand (Moreira and Goldemberg, 1999), much of it used in flexfuel vehicles, which can operate under different gasoline-ethanol blends (eg. E10 - 10% ethanol: 90% gasoline). In terms of vehicle fuel economy, one liter of ethanol equates to about 0.8 liters of gasoline (Kojima and Johnson, 2005). (ii) 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 very fast (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 (B100) or blended with diesel oil (EPA, 2002).

Without subsidies, the production of liquid biofuels is rarely economic.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C, E	Not yet known	G	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 and US$0.41 per liter of gasoline equivalent (*versus* US$0.45 and US$0.85 per liter in USA and Europe), but dependent on the world price of sugar and the exchange rate of the Brazilian currency. Brazilian ethanol production can be competitive with oil prices at about US$45-50 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 in order to make biodiesel 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 (Australian Government Biofuels Task Force, 2005; European Commission, 2005; Henke et al., 2005; Henninges and Zeddies, 2006; Hill, et al., 2006; IEA, 2004; IEA, 2006c; Kojima and Johnson, 2005; Kojima, et al., 2007; OECD, 2006; Worldwatch Institute, 2006).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	0 to +2	G	Wide applicability

Both small-scale biomass digesters and larger-scale industrial applications have expanded in recent decades. The generation of electricity (44GW [24GW in developing countries] in 2005 or 1% of total electricity consumption) and heat (220GWth in 2004) from biomass is the largest non-hydro source of renewable energy, mainly produced from woods, residues and wastes (REN 21, 2006). 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 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 (DTI, 2006; FAO, 2004; IEA, 2006a; Martinot, et al., 2002; Quaak, et al., 1999; REN 21, 2005). The biological technologies include the 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; World Bank, 2005). 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 were some 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
4	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 (IEA, 2006b; REN 21, 2005; WADE, 2004; World Bank, 2005). In combined heat and power mode, when capital investments can be shared between electricity and heat generation, electricity generation costs can drop to US$0.05-0.07/kWh, depending on the value of the heat (IEA, 2006b; REN 21, 2005). Thermo-chemical gasification can have higher generation costs (US$0.07 -US$0.46/kWh). Low capacity utilization due to weak electricity demand and technical failures caused by improper handling and maintainance can lead to even higher production costs (Banerjee, 2006; Ghosh, et al., 2006; Larson, 1993; Nouni, et al., 2007; World Bank, 2005). Data on electricity production costs with anaerobic digesters is not widely available, owing to the fact that most digesters are not installed commercially but through government programs favoring (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).

3.2.3. Livelihood improvement, empowerment and capacity building

The contribution to and impacts of AKST on productivity, natural resources and the environment have been discussed in subchapters 3.2.1 and 3.2.2. The focus of this subchapter is the examination of the contribution of technologies and methodological innovations to strengthen and support livelihood improvement, learning and empowerment. The discussion relates in particular to human nutrition, health and livelihoods, the reduction of hunger and poverty and enhanced social sustainability.

3.2.3.1 The contribution of AKST to livelihoods improvement

Assessing the evidence for the contribution of agricultural science and technology to improving livelihoods and empowerment is complex. While there is evidence of AKST contribution to increasing productivity of agriculture and sustainability of natural resource use, the extent to which this translates into improved livelihoods and for specific groups of people, is more complicated, involving discussion of differential impacts between and within populations. The difficulty of attribution applies similarly to negative outcomes associated with some AKST. Nevertheless, there is evidence that agricultural productivity growth has a substantial impact on poverty reduction although this is conditional on.equitable land distribution (Thirtle et al, 2003)

The Livelihoods framework is a useful contribution to the conceptual and methodological innovations, which are part of AKST.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	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 is noteworthy in linking the notion of sustaining the means of living with the principle of environmental sustainability. “A livelihood is 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, adapted from Scoones, 1998). The elements of the livelihoods framework which are highlighted for analysis include the assets that people combine and use to make a living (natural, social, human, physical and financial), the factors which cause vulnerability; the policies, institutions and processes which constitute environment within which livelihoods are pursued; the particular 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 2006). More recently it has been used to assist evaluation of outcomes and impacts (Ashley and Hussein, 2000; Adato and Meinzen-Dick, 2002; Meinzen-Dick et al., 2004). 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 the required balanced partnerships to promote local empowerment, resiliency and diversification (Butler and Mazur, in press).

3.2.3.1.1 AKST and poverty

Some gains have been made in 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
3, 6	B	-2 to +3	R, N, L	Africa is still the biggest problem

Worldwide, the numbers of people earning US$1 per day were 1,269 million in 1990-92 and have fallen to 1,134 million in 1997-99. Poverty is still a serious global problem. 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, 2006); 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 sub-Saharan Africa) have gained proportionately less than some richer countries (USA and Europe). Similarly, major benefits have escaped marginal agro-ecological regions (rain-fed dryland areas) and marginalized people (small-scale farmers, landless people, seasonally mobile populations, women and the poorest) (Lipton, 2003; Hazell and Haddad 2001; Fan et al 2000).

Detailed impact assessments of AKST's contribution to livelihood improvement are generally lacking

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	0 to +3	G, R, N, L	Wide applicability

Past assessments of impact of specific AKSTs have documented adoption, productivity increases and financial returns (Evenson and Gollin, 2003a). However, indirect impacts in relation to ownership of assets, employment on and off farm, vulnerability, gender roles, food prices, nutrition and capacity for collective action are less well researched (Meinzen-Dick et al., 2004; Hazell and Haddad, 2001). Recent studies have more comprehensively addressed these issues. For example, a program using participatory methods applied a sustainable livelihoods approach in Kamuli District, Uganda to strengthen farmers' capacity to learn from each other, found that farmer group households defined as food insecure decreased from 45% to 10% in 18 months up to mid-2006, with a reduced number of food insecure months. In addition, the production and variety of foods had increased. Households with poor nutritional status decreased from 38% to 17% during the same period (Sseguya and Masinde, 2006; Mazur, Sseguya, Masinde, Bbemba and Babiyre, 2006; http://www.srl.ag.iastate.edu/news/report.html).

Modern varieties bred on research stations have not always been well adapted to local conditions and/or have not been of acceptable quality or utility.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3	B	+3	G, R, N, L	Wide applicability

The success of the Green Revolution was, at least initially, a result of its focus on more favourable irrigated rice and wheat systems (Huang et al, 2002). The wide adaptation breeding and testing approach did not work so well when the focus shifted to more marginal and variable environments. Similarly, many modern varieties did not always meet farmers' requirements in terms of multi-purpose uses, e.g fodder and seed, or did not have acceptable post-harvest characteristics (e.g. easy to thresh/process, good taste, good storability). For example, literally hundreds of rice varieties have been released in India, but comparatively few are grown by farmers (Witcombe et al., 1998). Conversely, the most popular peanut variety grown in southern India was a Traditional Variety first identified in the 1940s (Bantillan et al., 2003).

Farmers do not always benefit from the products of crop breeding.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	B	-2 to 0	R	Widespread

Although the adoption of modern varieties is widespread, up to 70% in some crops (Evenson and Gollin 2003a/b), many of these varieties may nonetheless be relatively old and farmers are therefore not benefiting from the latest research on pest/disease resistant and yield. For example, in the Punjab the most commonly grown wheat and rice varieties have been found to be 8-12 and 11-15 years old, respectively (Witcombe 1999; Witcombe et al.2001). If annual genetic gains in potential yield are 1-2%, this means these farmers are losing potential yield gains of 16 – 30%. These losses could be even higher if modern varieties have superior disease or pest resistance (Oerke, 2006). More often than not, it is inefficiency in the varietal release system that limits the adoption of newer varieties (Witcombe et al., 1988). Participatory approaches can help overcome this inefficiency (Uphoff, 2002).

Livestock are important for rural peoples' livelihoods, however, livestock technologies have made only a limited contribution to improving the livelihoods of the world's rural poor.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 6	C	1-3	N, L	More positive in rich countries.

The rapid growth in demand for and consumption of livestock products in developing countries has been met largely through increases in livestock numbers rather than through productivity increases (Delgado et al., 1999). Important developments in livestock technologies are widely used in the developed world, but to a much lesser extent in the poorest parts of the developing world. In the former, feed technologies have contributed to productivity in intensive livestock production systems; biotechnologies in breeding for commercial pigs and poultry and artificial insemination and embryo transfer are widely used. However, there are constraints to applying these technologies in developing countries (Madan, 2005). In developing countries, vaccination against major animal diseases, e.g.

rinderpest, has made an important contribution. Reasons for the limited technology uptake in developing countries relate to higher financial and labour demands and also to an overly narrow technical focus rather than taking into account the social context of production, patterns of ownership and local knowledge (ILRI?). An examination of 6 tsetse eradication control projects found some success, although considered these were more rhetoric than reality (Dransfield et al., 2001). They advocated a more farmer-based and demand-driven approach to control. Group cohesiveness was found to be essential for collective action.

Impacts on poor livestock producers have mainly been through the introduction of new institutional forms.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	C	0 to + 4	L, N	Mostly in developing countries

A review of the potential for livestock interventions to reduce poverty (Livestock in Development 1999) examined donor experience with different approaches to support to the livestock sector. Many of the projects examined had not had satisfactory long-term impact on the livelihoods of the poor. The findings have indicated the importance of institutions in defining the success of pro poor measures; where institutions do not support poverty reduction, projects are likely to be limited in impact on the poor or on sustainability of systems. New institutional forms that have show success include the formation dairy cooperatives in India (Ramaswamy 1996).

3.2.3.1.2 Health and nutrition

Rates of hunger have been decreasing but are still common despite the advances of the Green Revolution

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	A	-3 to 0	R	Mostly in developing countries

Although the Green Revolution has had some impact on increased food supply its benefits (in terms of reduction of hunger and malnutrition) have been distributed unevenly across world regions. In 2005, it was estimated that hunger still affected 850 million people of whom 780 million were in developing countries (FAO, 2005). The number of people defined as hungry has been decreasing; one estimate is 815 million people in 1990-92 to 777 million in 1997-99 (von Braun, 2005). This is associated with a concomitant rise in the average world food supply and consumption per person from 2358 kcal per day in the mid 1960’s to 2803 in late 1990’s (FAO, 2005). However downward trends in the incidence of hunger have not occurred in many sub-Saharan countries of Africa (FAO, 2005), where population growth (3%) outstrips increases in food production (2%) (Anwar, 2003). Hunger is not explained by a simple relationship between food supply and population. Hunger occurs in populations unable to meet basic food needs mainly due to poverty and political instability not simply adverse agricultural conditions (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

1, 2, 3, 5	A	-4 to -2	R	Mostly in developing countries

Child malnutrition, measured by stunting, reduced in developing countries from 47% in 1980 to 33% in 2000 (de Onis, 2000). But it 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 dietary nutrients due to poor diet diversity, as well as 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, 2003). In the WHO Global Burden of Disease study, underweight attributed for 9.5% of total world disease burden (responsible in developing countries for nearly 50% of malaria, respiratory and diarrhoeal diseases) and selected dietary micronutrient deficiencies (iron, vitamin A and zinc deficiency) were responsible for 6.1% of world disease burden (Ezzati, 2003).

AKST has negatively contributed to a rise in overweight and obesity in developing and developed countries

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	A	-5 to -3	G	Worldwide

There are now more people overweight than underweight worldwide. In 2005 it is estimated that 1.6 billion adults (age 15+) were overweight, 400 million adults were obese and 20 million children (under 5) are overweight (WHO, 2005). Once considered a problem only in high-income countries, overweight and obesity are now dramatically on the rise in low- and middle-income countries, particularly in urban settings. Current overweight and obesity levels range from below 5% in China, Japan and certain African nations, to 40% in Columbia, Brazil, Peru (IASO, 2006), and over 75% in the Pacific. But even in relatively low prevalence countries like China, rates are almost 20% in some cities (WHO 2003). In Thailand the prevalence of obesity in 5-to-12 year olds children rose from12.2% to 15-6% in just two years (WHO 2003).

AKST focus on increasing production rather than diet quality has ignored major causes in diet-related disease worldwide, contributing to a double burden in developing countries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5	A	-4 to -2	G	Worldwide

The AKST focus on energy needs, rather than improved nutrition and access to a balanced and healthy diet, has not tackled high rates of micronutrient deficiency diseases and has been one factor in increasing overnutrition and obesity worldwide. A dietary transition has occurred in many developing countries that are experiencing demographic and socio-economic transition (Caballero, 2005). Changes in food availability and lifestyle (e.g. urbanisation) are resulting in low intake of fruits and vegetables and high intakes of meat, sugar and salt. This is leading to a rapid rise in other diet-related chronic diseases such as obesity, diabetes, hypertension, heart disease and cancers globally (WHO/FAO, 2003). This recent dietary transition has now brought a double disease burden due to undernutrition and overnutrition coexisting in a wide range of developing countries in Africa, Latin America and the Pacific (Caballero, 2005; Vilosof, 2001; Vorster, 2005).

AKST has been slow to incorporate the increasing scientific awareness of the relationships between diet, nutrition and health into agricultural policy and practice.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5, 6	A	-3 to -1	G	Worldwide

There is international agreement on the requirements of a healthy diet (WHO/FAO 2003). For example: diets rich in fruits and vegetables have been shown to be important in preventing a range of diseases e.g. in reducing night blindness and morbidity (Talukder et al., 2000; Bouis, 1991); lowering the risk of heart disease, stroke, and many cancers (Ness and Powles, 1997; WCRF, 1997; Lock et al., 2005; Bazzano et al., 2005; improving maternal nutrition and birth weight of children (Rao et al., 2001). Mungbeans and common beans have been used in reducing anemia (Vijayalakshmi et al. 2003). In contrast, 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. Monounsaturated fatty acids have a positive health effect but it is essential that monounsaturated fatty acids be mainly supplied by plant oils like rape seed or olive oil (Wahrburg 2004).

Dietary diversity has been recognized as a key element of a healthy diet.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5, 6	B	+2 to +4	G	Worldwide

Many studies have recognized dietary diversity as a key positive element of food quality or balanced diet essential for optimum health (Randall et al., 1985; Krebs-Smith et al., 1987; Hatloy et al., 2000; Marshall et al., 2001). With the increased focus on staple starch crops, dietary diversity has declined over recent decades, and become a research priority (Hatloy et al., 2000; Marshall et al., 2001; Hoddinott and Yohannes, 2002). For example, how does dietary diversity affect: (i) the risk of esophageal cancer (e.g., Tuyns et al., 1987) vascular disease (Wahlquist et al., 1989), other cancers and cardiovascular diseases (Veer et al., 2000 and Cox et al. 2000 on); (ii) birth weight of children (Rao et al., 2001), (iii) overall health (Ruel, 2002), (iv) life span and mortality (Kant et al., 1993), and (v) earning capacity from manual labor (Ali and Farooq, 2004; Ali et al., 2006).

Urbanisation and the global trend towards diet simplification with reduced supplies of fresh food have negative consequences on food diversity and security, nutritional balance, and health.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,2, 3, 5, 6	B	-4 to -2	G	Worldwide

Increased population pressures on forests and woodlands has led to the decline in the reliance of the poor on gathered food from these natural sources (IPGRI, 2005), which are often rich in major and minor nutrients, vitamins and minerals (Leakey, 1999). Similarly, increased urban infrastructure pressure on urban and peri-urban agriculture land has reduced the fresh sources of food supply from home gardens (Ali et al., 2006). The neglect of policies to promote the development of traditionally and nutritionally important indigenous fruits and vegetables has reduced the frequency of these crops in both the cropping system and the diet. These trends are reinforced by the nutrition transition worldwide resulting in expansion of the 'fast-food culture' and lack of time for home gardening and food preparation due to the increased proportion of working women.

Food based approaches to tackle micronutrient deficiencies (such as iron, vitamin A, iodine) have long term benefits on health, learning ability and productivity.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	+2 to +4	R	Mainly in developing countries

New food based approaches to tackling micro-nutrient deficiencies are being developed which focus on food production, diet diversification and food fortification. However the potential of food based strategies to reduce micronutrient deficiency disease has not been fully explored or exploited (Ruel and Levin, 2000). They are potentially more cost effective and sustainable than treating people with food supplementation options as they give greater attention to diversified production of fruits, vegetables, oilcrops and grain legumes, especially traditional foods, as well as meat, fish and dairy products (FAO, 1997).

AKST has not promoted the food security of the rural poor.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	-4 to -2	R	Rural poor in developing countries

Rural poor (who comprise 80% of those hungry worldwide), especially women, 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, animals and other forest foods are important to the diet and food security of an estimated 1 billion people (FAO, 2005a). The growth in rural areas and in the agricultural sector has a much greater impact on reducing poverty and hunger than urban and industrial growth. Nevertheless, research and development policies have most often favoured large-scale, industrial production of crops and livestock at the expense of mixed farming systems employed by the poor. They have also paid too little attention to the fact that female labour force is deeply engaged in food production, and that better education and technological empowerment of women directly leads to significant improvement in their children nutrition and family health (FAO, 2005).

Both health benefits and disbenefits have resulted from AKST in post-harvest food processing technology and practice.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5, 6	A	-2 to +2	G	Worldwide

The emphasis of current post-harvest research is on reducing the transmission of food borne infectious disease. Many countries have adopted food safety practices and standards arising from AKST. For example, developing reliable and quick detection methods for human pathogens; cost-effective methods for reducing microbial load on intact and fresh-cut fruit and vegetables; improved efficacy of water disinfection methods, such as chlorination/ozonizations (Kader, 2003), or vapor heat treatments to minimize the microbial contamination, and on improving food chain processes (e.g. HACCP). More recently, emerging infectious diseases, such as Bovine Spongiform Encephalopathy (BSE) in cows and H5N1 (Avian Influenza) in poultry have entered the food chain as animal infections but have been transmitted to humans as new diseases due to poor agricultural practices. Research is also underway to investigate fears that the overuse of antibiotics in animal feed may lead to the development of drug-resistant pathogens, causing animal micro organisms to transfer their drug-resistant genes to a human bacterial strain, or mutate to become infectious in humans.

The health focus of post-harvest processing has mainly been has been on adding value and increasing shelf-live, and not on improving nutrition.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5, 6	B	0 to +3	G	Worldwqide

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. Worldwide there has been a huge increase in the consumption of such processed high fat, high salt, foods which are having negative impacts on health (Nestle, 2003). Studies demonstrate that processing even reduces the nutritive value of most fruits and vegetables (Wills, 1998; Shewfelt and Bruckner, 2000). Post-harvest treatments to extend shelf life degrade provitamin A, such as β-carotene, and reduce the bioavailability of nutrients (Zong et al., 1998; AVRDC, 1987). The benefits of food processing technology also tend to be unequally distributed, with rural producers of raw foods receiving increasingly lower percentages of the final processed food costs. With emphasis on ‘adding value’ food retailers have had no incentive to promote healthy fresh produce such as fruits and vegetables. Recent technology has started to develop processed foods that are specifically aimed at promoting health, e.g. growth of functional foods with health claims (Hasler, 2000). However they are predominantly aimed at rich consumers.

Agrichemical use can have adverse health impacts, both acute poisoning (intentional and accidental) and effects due to long term occupational exposure.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 3, 5	A	-3 to 0	R	Mainly in developing countries

Agrochemicals have been responsible for increasing food production and in the control of some important human diseases such as malaria. However, they can also cause a wide range of health problems from mild illness such as skin irritation to a range of serious acute and chronic symptoms (O’Malley, 1997). It has been estimated that at least 3 million cases of pesticide poisoning occur worldwide each year. One million of these are thought to be unintentional poisoning and 2 million suicide attempts, with 220,000 deaths (WHO, 1986). The majority of these 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). Acute poisoning of agricultural workers from improper handling of pesticides poses a significant public health risk that is linked to factors such as insufficient access to high-quality protective gear, poor product labelling, and low worker literacy rates (Repetto and Baliga, 1996). In industrialized countries, traces of herbicides such as 'Atrazine' and other potential carcinogens are routinely documented in ground and surface waters adding to the risks of non-occupational unintentional poisoning (Barbash et al., 1999).

Inadequate attention is given to the impact of poor health on agricultural productivity and application of AKST.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	A	-4 to -2	R	Mainly Developing countries

If poor health, resulting from a range of causes including malnutrition, chronic non-communicable diseases and infectious diseases, is prevalent amongst agricultural workers then agriculture production can be negatively affected (Jayne, 2004; Croppenstedt, 2000). Ill health amongst families of producers can also impact on production through absenteeism to provide health care, and the loss of household income or other outputs of farm work (Jayne, 2004). Poor health also impacts on farmers' ability to innovate and develop farming systems (Jayne, 2004). In developing countries these issues are most clearly illustrated by the impact of HIV-AIDS (Fox, 2004; Jayne, 2004). Many studies show that communities with high prevalence of the disease experience financial and labour shortages, switching crop types, reducing the area of land under cultivation and leading to decreasing productivity (Fox, 2004; Jayne, 2004). HIV-AIDS, due to reductions in life expectancy, also results in loss of local agricultural knowledge and reduced capacity especially with respect to uptake of AKST.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	A	-2 to 0	R	Developing countries mainly

Access to clean drinking water is estimated to be responsible for nearly 90% of diarrhoeal disease in developing countries (Ezzati 2003). Although only Africa is not on track to meet the MDG drinking water targets for clean water, water is still a scarce resource and a major health issue. In some areas of the Sahel, aquifers are becoming seriously polluted by a nitrogen pulse descending to the water-table, which can be more than 30m below the soil surface (Edmunds et al., 1992; Edmunds and Gaye, 1997). This nitrogen is probably of natural origin, since nitrogen-fixing plants used to be dominant in natural vegetation and, in the absence of disturbance, the nitrogen was probably recycled in the upper soil profile through leaf litter deposition and decomposition. However, following deforestation, the recycling process is lost and the nitrogen is slowly leached down the profile, with serious implications for the future potability of the groundwater for the human population and the livestock of nomadic herdsmen.

3.2.3.1.3 Livelihood strategies – diversification, specialisation, migration.

Survival of established cultural traditions may define the essential values of a smallholder community that follows low-input and risk-averse strategies.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread in tropics

Smallholder producers make rational decisions to maximize overall benefits from limiting resources (Ørskov and Viglizzo, 1994). So, 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 (Conway 1997).

When the population pressures reach a point where farm size or productivity can no longer sustain the needs of the household, **alternative strategies of migration or investment occur**.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +2	G	Widespread in tropics

When this happens, some family members migrate to urban centers in search of employment. These decisions are affected by generational and gender relationships (Chant, 1992, Tacoli 1998, Bryceson, 1999). Migrants are very often men, particularly young men. This contributes to the feminization of agriculture (Song 1999; Abdelali Martini et al., ????), but migrants increasingly include young women, leaving the old and the very young on the farm. At this point, labour constraints encourage investment in technologies and options which are less demanding in labour, e.g the establishment of tree crops which are profitable with lower labour inputs. There is also some evidence for other aspects of more sustainable farming at very high population densities, such as erosion control (Tiffen et al., 1994; Leach and Mearns, 1996)

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +4	G	Especially in the tropics

Diversifying income sources to include non-farm income can be a risk reducing strategy for rural households. However, this is more difficult for the extreme poor including female-headed households (Block and Webb 2001). Some have argued that in Africa the increasing proportion of rural income from non- agricultural sources is indicative of the failure of agriculture to sustain the livelihoods of the rural poor (Bryceson, 1999; Reardon, 1997; Ellis and Freeman, 2004). There is evidence that the larger the proportion of non-farm to farm income, the larger the overall income. Diversification affects agricultural productivity in different ways, in some cases positively (Ellis and Mdoe, 2003). It can be seen as a response to an environment in which the conditions needed to reap the benefits of agricultural specialisation; enterprises with efficient market integration, input and credit supply systems, knowledge access, relatively stable commodity pricing structures and supportive policies - are lacking (Townsend, 1999).

Displacement of population is an impact of large-scale irrigation schemes.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-3 to 0	G	Wide applicability

The displacement of populations is one of the notable consequences of irrigation schemes. Dams have fragmented and transformed the world's rivers, displacing 40-80 million people in different parts of the world (WCD 2000). As a result of uneven sharing of water resources, 'water wars' have emerged in many countries, as for example in Mozambique which shares nine river basins with nine upstream countries - Zimbabwe, South Africa, Zambia, Botswana, Malawi, Tanzania, Swaziland, Angola and Namibia (van der Zaag et al., 2002, 2003).

An outcome of increased agricultural productivity is an increase in the educational status of children as investment is made in human development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	0 to +4	G	Wide applicability

A positive impact from successful AKST is improvements in education and employment – both on and off farm. Figures on enrolment in primary education show progress across developing countries (86% overall), particularly in southern Asia where the figure is 89% (UN, 2006), but less improvement in some countries of Africa, western Asia and Oceania. There is a wide gender gap in primary school attendance; one in five girls are not in school compared with one in six boys. Numbers of children out of school are much higher in poor rural areas (30%) compared to urban (18%). There have been advances in off-farm employment opportunities. However, the share of women in non-agricultural wage employment has not greatly increased between 1990 and 2004 (UN, 2006) and youth unemployment rates have increased. Since 1995, the number of young people worldwide has grown by 135 million and youth unemployment has risen from 72.8 to 85.7 millions. Young women in particular, have difficulty in entering the labour market.

3.2.3.1.4 Access to resources

Access to land, 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
3, 5	A	0 to +5	G	Especially in the tropics

Households with land are generally better placed to make productive use of their own resources (especially labour), as well as to access capital for investment (Deininger, 2003). Conversely, processes of 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). In many countries, particularly in Sub Saharan Africa, there is a plurality of systems of authority related to land. The main contrast is between customary and statutory law, although these categories mask multiple secondary rights. In his influential 'tragedy of the commons', Hardin (1968) identified communal land tenure as inimical to investment because of tenure insecurity. Policies and programmes which have made efforts to establish individual rights in land through land titling have not produced clear evidence showing this has led to greater agricultural growth (Quan, 2000) and in some cases it has led to increasing landlessness and poverty. Customary land tenure systems are challenged by competition from expanding populations, urbanization and commercial development. Without supportive policies, it is difficult for poor small holders to enter emerging land markets (Toulmin and Quan, 2000). Other strategies explore alternatives which 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 decentralised policies and institutions for land and land rights management.

3.2.3.1.5 Local entrepreneurship and value added

Agricultural and non-agricultural businesses interact in the rural economy; therefore any policy to reduce poverty and improve the rural environment has to take into account the holistic nature of decision making.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5, 6	B	0 to +4	G	Especially in the tropics

It is important to maintain a broader vision of agriculture that demands: (i) farmers acting within an agricultural production-trade chain; (ii) dynamic links to social, economic and environmental activities in the region; (iii) original development plans according to the heterogeneity of agriculture among countries; and (iv) recognition of the differences of the farming methods and cultural background. Many farmers in developed countries now have a much better understanding of the nature of the demand that they are responding to – in terms of its implications for varieties, timing, packaging and permitted chemicals. As a result, they have progressively modified their production practices and their portfolio of products in response to changing patterns of demand. Knowledge-based approach has not yet been adopted widely in developing countries, beyond a relatively small group of educated commercial producers (FAO, 2001)

3.2.3.2 Participation and local knowledge systems

3.2.3.2.1 Participation and participatory planning

There has been a growing recognition that conventional approaches to developing rural technologies have not been entirely successful.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-3 to +2	G	Widespread applicability

This recognition has developed into a criticism of the technology transfer model, and has led to considerable interest in alternatives based on a participatory approach. These participatory ideas and the associated rhetoric form a major component of what has been described as a new development paradigm (Jamieson, 1987). The participatory approach uses existing local skills and knowledge as a starting point, and is built around a process that enables farmers to control and direct research and development that meets their own needs. In this process development agencies and technical specialists are participating in a process that is managed by farmers, rather than farmers participating in something the outsiders are controlling and managing (Croxton, 1999; Odhiambo, 2002). For the farmers, this generates a sense of ownership of decisions and actions. There are however, concerns about how to scale up, especially when an institutional ‘enabling environment’ is missing.

New methodologies have been developed that place farmers at the centre of AKST partnerships.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	0 to +4	G	Especially in the tropics

These new tools include: participatory technology development, farmer field schools, participatory plant breeding/domestication, participatory innovation development and others. There is a growing body of work that seeks to assess systematically the impacts of participatory and gender sensitive approaches in agricultural research and development. The Participatory Research and Gender Analysis Progam of the CGIAR is a major example (Lilja, 2001). Case study examples include local agricultural research committees (CIALs) in Colombia where preliminary results showed significant social and human capital benefits for CIAL members (agricultural learning, new skills, experimentation, improved communication and leadership skills, wider social relationships and community involvement). http://www.prgaprogram.org/index.php?module=htmlpages&func=display&pid=12

Participatory methods have become important in all aspects of agricultural development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	0 to +3	G	Especially in the tropics

The production of KST is a social and institutional process that makes technology a factor of transformation. Participation is a process through which stakeholders influence and share control over development initiatives and the decisions and resources which affect them, so making agricultural technology development more effective (Engel et al., 1988). Multi-stakeholder participatory planning institutions use participatory processes to renegotiate the ‘4Rs’ (rights, responsibilities, returns and relationships – Dubois, 1998) of forestry and agricultural institutions (Dalal-Clayton and Bass, 2002) to improve commitment and ‘ownership’. Research has shown the need for caution (Cooke and Cothari, 2001), when transferring participatory initiatives from one place to another

Participatory approaches to genetic improvement of crops and animals results in better identification of farmer’s requirements and preferences, leading to better adoption and release.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Wide applicability

Since 1997, the work of the CGIAR Systemwide Program on Participatory Research and Gender Analysis has developed and shared participatory methods in plant breeding and varietal selection (Saad, 2003). They have collected evidence to show how participatory methods are producing technologies and resource management options that are well suited to end-users’ needs. The advantages include: better identification of farmer’s requirements and preferences for their own systems of production; quicker release to farmers fields; local adaptation in farmers’ fields (G x E interactions); rapid adoption by farmers and compatibility with informal seed systems. Genetic diversity can also benefit as farmers usually select and introduce cultivars that are unrelated to those already grown (Witcombe et al., 2001). The shortened breeding cycle of the participatory approach typically gets new varieties to farmers prior to multi-locational testing and formal release, considerably increasing cost-benefit ratios (Pandey and Rajatasereekul, 1999).

The mechanisms by which participatory approaches are beneficial are not always clear.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-2 to +4	G	Published examples

A study on the Impact of Participatory Natural Resource Management Research in cassava based cropping systems in Vietnam and Thailand (Dalton et al., 2005) found that there were additional yield benefits experienced by the group involved with participatory approaches. A possible explanation for this is that participatory research activities improved farmers' understanding of the interrelationships between system components and led to efficiency gains based on management modification. The learning aspects of participatory approach may have increased their ability to respond to and moderate production stresses.

Participatory approaches to pest/disease/weed management and to crop and tree domestication, involve stakeholders at every step of the technology development process.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	R	Widespread in the tropics

This allows modifications to the technology which meet the economic and socio-cultural needs of the community, engendering ownership of the technology by working in partnership with local people and thus encouraging its adoption. Farmer-to-farmer visits between communities greatly enhance the dissemination of new technologies (Tchoundjeu et al., 2006) – this technique has been beneficial also to the dissemination of participatory domestication between countries (e.g., Cameroon to Equitorial Guinea).

Participatory approaches to livestock research have demonstrated the importance of understanding the particular needs and circumstances of resource poor farmers and building on local knowledge

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +2	R	Especially in the tropics

These approaches have helped to ensure that the technologies developed and promoted are appropriate to farmers' circumstances and are more likely to be relevant and adopted (Conroy, 2005; Catley, 2001).

The successful achievement of Development Goals is greatest when technology development and dissemination considers socio-cultural integration as a key component of scientific developments and ensures that resource poor farmers are involved in problem-solving through demand-driven and needs-based analysis.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +4	G	Widespread in the tropics

Participatory research approaches have strongly emphasised the issues around human and social capital, which are essential to the sustainability of rural development and innovation, particularly with respect to the management of common pool resources (Saad, 2003). A World Bank report on the irrigation sector of India describes the problem of poor performance of irrigation systems as a "vicious circle" of inter-related technical, socio-economic and policy issues that have prevented improvements (World Bank, 1999). A review of hydrology and watershed management projects in India found community interest/involvement and government policy to be major factors for project success and that these factors present the most difficult challenges for project staff (Kumar, 2003; Reddy, 2003; Sharma, 2003a; Sharma, 2003b).

Behavioural and sociocultural variables of resource management are important for sustainability.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	0 to +4	G	Widespread applicability

The management of natural resources, including water for agricultural use, requires an understanding of social and behavioural components of their use and relationship with AKST. (http://www.cgiar.org/publications/pub_secretariat.html). For example, water rights change, evolve and adapt over time. There is no single pathway for changes in water allocation but there has been a tendency for new agencies to take on increasing roles in water allocation, through private transactions, with users trading water through short or long-term agreements, and reallocating rights in response to prices. Markets thus may also play a valuable role in facilitating the voluntary transfer of water to higher value uses, but this requires a suitable enabling framework that recognizes the importance of agriculture (Bruns and Meinzen-Dick, 2003, citing Meinzen-Dick and Rosegrant, 1997).

The relevance and importance of social issues has also been cogently illustrated in conservation programmes.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +2	G	Widespread experience

Without participation of the range of stakeholders in consensus building and consideration of the distribution of benefits, the potential for conflict and the challenges to sustainability are increased, as are the economic costs of implementation and control (Borrini-Feyerabend, 1997; Guerin, 2006).

Initiatives to enhance social sustainability are strengthened if accompanying social policies can help to ensure the poorest can participate.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +4	G	Widespread in the tropics

For example, programmes on asset building or asset transfer and supporting programmes for human capital development, health care, literacy and employment (particularly in off farm enterprises), all empower poor people in the community (UNDP, 2006; IDS, 2006). The alternative scenario to such investments may be one of increased cost of mitigating the impact of livelihood and natural resource failure in poor rural areas through long-term welfare support and emergency relief (Dorward et al., 2004).

Collective resource management groups involving communities have become increasingly common, aimed at building trust and social capital.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY

3, 5	B	0 to +4	G	Widespread in the tropics

Since the early 1990's, about 0.4-0.5 million local resource management groups have been established, 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. However, some associations can have negative impacts when unduly manipulated by individuals with self-interest (Pretty, 2003; de Sardan, 1995)

Community participation in decision-making is important for social cohesion.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	0 to +4	G	Widespread applicability

Participatory Systems thinking which emerged in 1980s, includes new concepts about diversification and multi-functionality at the household level; livelihood systems, innovation systems; etc, that are driven by concern about achieving wider dissemination and use of technology. This approach is important as it enhances: (i) governance by making it possible to reach consensus and agreement among multiple stakeholders; (ii) prevent or resolve conflicts and (iii) strengthening ownership and relevance of support activities (Haverkort et al., 1991; Burns and Ambler, 1992; Okali et al., 1994; Scoones and Thompson, 1994; Cerf et al., 2000; Hamilton, 1995; Roling and Wagemakers, 1998). Participation and/or consultation with shareholders at community level might also help preventing conflict that could be exacerbated among neighboring countries sharing coastal resources.

The development of Participatory Technologies is a way of increasing the probability that AKST will be appropriate for resource-poor and smallholder farmers and that the criteria for successful implementation of community resource development projects is ensured.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread applicability

In an evaluation of the success of watershed development projects in India, Kerr (2002) indicated the critical need for:

(i) everyone, especially the poorest and politically weakest members of the community to obtain benefits;

(ii) project stakeholders select the measures that they really want for long-term benefits to ensure that their interest in the project is sustained.

(iii) monitoring and evaluation are essential for assessing project success. This is especially important to ensure the primary goals.

Participatory approaches in agricultural technology development include an understanding of the priority the poor place on managing risk.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread applicability

High levels of risk are likely to affect adoption (Menzien-Dick et al., 2004). Smallholder farmers often spread risk by diversification, as for example in mixed cropping systems (Dixon et al., 2001). However, perceptions of risk and the priorities of men and women will vary in relation to their asset base; land and labour in particular.

3.2.3.2.2 Local knowledge and innovation systems

In the last 15 years, the importance of knowledge in innovation processes has been more clearly recognised

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread

Knowledge is considered as a factor of production, considered by some to be more important than the other factors of land, capital and labour. Innovation is a complex social process (Engel and Röling,1989; Roling 1992; Luecke and Katz, 2003). The conception of technology development as a linear path from research through product development and testing to promotion and diffusion has been challenged by experience showing that the pathways whereby technical changes occur are more diverse. There are complex mechanisms and interactive relationships involving a range of institutions, networks and society, which develop the process of innovation which is necessary to bring about changes and a dynamic economy (Schumpeter, 1916; 1939). Innovations develop in multiple forms according to the stakeholders, space and time (Sibelet, 1995).

F**armers' innovations, particularly in small scale and smallholder agriculture remain largely unconnected and unrecognized by formal AKST, but have made important gains in intensification and sustainability.**

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +4	G	Especially in the tropics

Formal research and extension organisations often have not recognised the contribution of farmers' knowledge and strategies (Sibelet 1995; Richards, 1985), for example the response to an increase in population growth by an increase in agricultural production in a more sustainable environment. In plant breeding, Hocdé (1997) showed how farmers could contribute efficiently to the development of new plant varieties by communicating their local knowledge to researchers and being involved in the experimentation and decision making according to their needs. With stakeholders, researchers build a partnership able to define common objectives and to agree and design experimentation and to share and validate results in terms of knowledge and development (Gonzalves et al., 2005; Liu, 1997; 2006). Innovation models must evolve as a result of collective learning and need to constantly adapt in response to the turbulence originating from transition and from market forces.

The knowledge of many traditional communities provides 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
1, 2, 3, 5	A	+2 to +5	G	Worldwide

Such traditional KST has been developed through observation and experimentation, over many cycles, to achieve efficient and low-risk human welfare outcomes (reference). Typically it is codified in many oral forms, cultural/religious norms and farmer practice, rather than scientific hypotheses and associated legal instruments (Warren et al., 1995). A wide range of local institutions are significant in developing and disseminating and trying to protect this traditional knowledge as it contrasts sharply with both the specialised roles played by research and extension institutions working with agricultural science (reference). The actors associated with this traditional knowledge are comparatively marginalized by mainstream organizations. They also tend to harbour distrust of the mainstream organizations (reference). Identifying an appropriate and acceptable means of 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 from sharing their knowledge (reference).

An understanding of the complex dynamic interactions between society and nature and its resources in general has contributed to sustainable development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +4	G	Worldwide

Culture and tradition are critical components of social sustainability. For example, yams (*Dioscorea* spp.) play a vital role in society in the Dagomba ethnic group in N. Ghana, About 75% of farmers in the northern region of Ghana 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. Yams are a staple crop of economic and cultural significance for the Dagomba, associated with the celebration of the yam festival when boiled yams are smeared on the surface of stones to secure the goodwill and patronage of deities. The Dagomba also 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) breakdown of traditional social structure; (b) loss of valuable yam germplasm in many cases.

The important role of livestock for poor people’s livelihoods is sustained primarily through the effectiveness of local knowledge.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	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), providing a source of food, cash income, manure and draught power and strengthening their capacity to cope with income shocks (Ashley et al., 1999, Heffernan and Misturelli, 2001). In some countries, for example India, livestock holdings are more equitably distributed than land holdings (Taneja and Brithal, 2003). Livestock ownership directly and indirectly affects the nutritional status of children in developing countries (Tangka et al., 2000). The livestock sector in Africa, particularly in arid and semi arid areas depends to a large extent on local knowledge. This conveys advantages in terms of localised development 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 shown promise, both in characterisation of diseases and the linkages between local knowledge and modern veterinary knowledge (Catley et al., 2001). Such participatory local analysis was used to develop control programmes adapted to local conditions and knowledge (Catley et al., 2002).

AKST has in some circumstances been a strong driver/factor for exclusion/marginalisation processes.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-3 to +2	G	Widespread in the tropics

Although AKST has often had positive benefits on peoples' livelihoods, there have also been negative impacts (reference). This occurs because of differences in capacities to make use of knowledge and technology; differences in resource access; the impacts of technology use (e.g. Green Revolution) and the use of AKST to justify trade rules and regulations or property rights, etc. (reference).

Water resource management is enhanced when users participate in decision-making and control.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	0 to +3	G	Widespread applicability

Social reforms have included providing secure water rights for users and reducing or eliminating water subsidies. Farmers have proven to be willing and able to make substantial contributions to the construction and improvement of irrigation systems, when the projected benefits outweigh the costs. Their contributions create a stronger sense of ownership, leading to better subsequent operations and maintenance (Burns and Ambler, 1992). The better performance of farmer managed irrigation schemes was confirmed in a worldwide study of 40 irrigation schemes (Tang, 1992), and a study of over 100 irrigation systems in Nepal (Lam, 1998).

There has been a loss of social institutions at the community level, which is leading to the over-exploitation of natural capital.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 4, 5	A	-5 to 0	G	Widespread experience

In some cases this arises from changes in local systems of administration and governance, In India, for example, the breakdown of regulations about grazing livestock has resulted in unregulated grazing (Pretty and Ward, 2001), while the degradation of water resources has followed the replacement of collective irrigation systems with private ownership. The influence of social institutions for land management, based on local knowledge and norms may be undermined by policies based on the different perspectives of agricultural professionals. For example, one study for Thailand, Laos and Vietnam showed that the cause of many formal attempts to halt rotational shifting cultivation was, at its most fundamental level, a clash of KST – 'policy makers believed that shifting cultivation was the main cause of environmental problems such as floods and landslips' (Bass and Morrison, 1994).

Basing technology development on a sound understanding of the economic and social needs of resource poor farmers has led to simple, adoptable and appropriate agricultural technologies to address these problems.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread applicability

Twenty-five years of agroforestry research (Nair et al., 2004) have addressed increasing complex issues integrating biophysical and socio-economic disciplines to resolve the over-riding sustainability problems of agricultural development in areas where poverty and environmental degradation go hand in hand. This has required a unique mixture of new science (Sanchez, 1995) with understanding the day-to-day concerns of resource-poor farmers that affect their capacity to adopt new ideas and technologies (Franzel and Scherr, 2002). Farmers are often improving traditional systems of mixed cropping, so promoting low-input, risk-averse, environmentally-sound and easily adopted production strategies, which meet their needs for enhanced livelihoods and food security. Economists have developed techniques to quantify the economic returns from the multitude of products and services (social/environmental and local/global) derived from agroforestry (Pearce and Mourato, 2004) so capturing the total economic value, and these have been used to determine the 'best-bet' alternatives to slash-and-burn agriculture (Tomich et al., 1998; 2005).

3.2.3.2.3 Linking scientific and traditional knowledge and management capability

The establishment of organizations is a critical dimension of makng AKST sustainable.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +4	G	Widespread phenomenon

Innovations do not follow a straight path from basic research to development and implementation. Such linear models in which 'innovations' are transferred to users as products from researchers to farmers via intermediaries in extension, have recently been challenged by approaches which emphasize the participation of a diversity of key actors and organizations in any innovation and learning process (Spielman, 2005). In this view, innovation is about the relationships between heterogeneous actors through which new products and processes are brought into use. 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). Elements which are strongly emphasized in the approach are continuous learning and knowledge flows, interaction of multiple and diverse actors and institutional change.

The innovation systems approach offers greater insight into the complex relationships of sustainable rural development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread applicability

Innovation Systems thinking has encouraged greater awareness of the complex relationships between a diverse set of actors, processes of institutional learning and change, market and non-market institutions, public policy, poverty reduction, and socioeconomic development (Hall et al, 2003). However, the approach does not explicitly engage with the poverty and MDG agenda 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 needs to address the diversity of local situations.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Widespread applicability

At local level, a large body of literature has shown capacities of long-enduring local institutions to manage local resources and avert possible "tragedies of the commons" (Ostrom, 1992). Rules are created to involve the heterogeneity within communities (Agrawal, 1999; Ostrom, 2005) and opportunities of co-management with government (Balland and Plateau, 1996). However, the recognition of local management potentialities has in some cases led to rigid and top-down user associations with important functional and democratic short-comings (Agrawal, 2005). In the irrigation sector, irrigation management transfer has been a sweeping policy all over the world, but it has not necessarily led to better irrigation service and production at farm level. Research has shown what are the enabling conditions for a successful transfer, such as supportive legal-policy framework; secure water rights or local management capacity building (Shah et al., 2002). Finally, research has shown the high diversity of water rights, and the necessity to take into account local indigenous rights in many developing countries, thus with a legal pluralism approach (Bruns et al., 2005). In particular, market regulation of water allocation is much more promoted worldwide than actually implemented, and the much referred-to experience in Chile showed mixed results (Bauer, 1997).

The factors affecting adoption of technological innovations are numerous and complex.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5	B	0 to +3	G	Widespread applicability

They include economic, social, cultural and institutional issues, which result in a quantitative scale of adoption, rather that just adoption/non-adoption (Feder et al., 1985). Technologies that complement existing practices, and which form a progressive chain, are more likely to be adopted. The relative 'profitability' of alternative technologies also affects adoption, although these 'profits' are not necessarily financial. Agroforestry practices often have the attributes of adoptable systems (Franzel and Scherr, 2002), although because of its labour demands, hedgerow intercropping or alley farming has been an exception. Government policies can be either an incentive or a disincentive to adopt new technologies. Similarly the implementation or breakdown of community rules can affect the practices adopted by community members. Early adopters are not usually the most needy, but can encourage others to become adopters. The benefits of early adoption can create new opportunities for further progress. Initiatives that have sought to promote the inclusion and integration of local knowledge still require more emphasis on knowledge and skills of marginal and particularly of women.

3.2.3.2.4 Participatory crop breeding and the informal seed systems

Participatory approaches to plant breeding and varietal selection have become popular in recent years.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	C	+1	L	Widespread

In cereals and legumes, participatory approaches have been promoted in response to perceived weaknesses in conventional variety testing and release procedures which have not delivered suitable MVs to farmers, especially, but not exclusively, small-scale farmers in marginal environments (Witcombe et al., 1998). Formal release systems are often centralized, use research station or favourable environments for testing, and select for average performance. Farmers or consumers are also rarely involved in this process. MVs from conventional release systems are often poorly adapted to smallholder conditions and environments and have not always met farmers' requirements in terms of multi-purpose uses, e.g fodder and seed, or did not have acceptable post-harvest characteristics (e.g. easy to thresh/process, good taste, good storability). Participation allows for the better identification of farmers' requirements and preferences for their own systems of production and exploits Genotype X Environment interactions. Genetic diversity can also benefit from participatory approaches as farmers usually select and introduce cultivars that are unrelated to those already grown (Witcombe et al., 2001). A further important benefit is that MVs introduced in this way support and enhance local or informal seed systems, which are very important under normal circumstances but especially so in times of extreme stress, whether climatic or otherwise. However, all these benefits are largely experienced at local or regional levels where participatory programmes are based, and the problem of scaling-up remains.

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 5, 6	D, E	0 to +2	R	Especially relevant to the tropics

Throughout the tropics there are local tree species, which provide traditional foods and medicines (Abbiw, 1990; Villachica, 1996; Walter and Sam, 1999; Leakey, 1999). These 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., 2005). The use of participatory approaches is done to ensure 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 can shorten the time from hybridization to release.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	C	+1	L, R	Widespread

Conventional plant breeding cycles are typically about 12 to 15 years from the initial cross to release following multi-locational testing. Pandey and Rajatasereekul (1999) carried out an economic analysis of a plant breeding programme in NE Thailand using Net Present Value (NPV) and the concept of net social benefit. This analysis showed very clearly that there was a major benefit to shortening the breeding to release cycle. So, with a maximum area of 1.8 m ha, a yield gain of 10% and a discount rate of 10%, shortening the cycle from 13 to 11 years raised benefits by $18.1 m or $10/ha; one less year (i.e. 10 years) and benefits were increased to $28.5 m. Raising yield potential from 10 to 15% gave a $70 m benefit. Participatory plant breeding programmes can shorten the breeding cycle by several years by getting MVs to farmers sooner, usually prior to multi-locational testing and hence release. Other benefits of participatory approaches maybe higher yield (local adaptation and exploitation of G $\times$ E), higher adoption ceiling (farmers select and like the MV), and faster adoption (participatory programmes can target slower adopters). All of these factors, singly or together, will result in more pay off to the breeding programme.

Local or informal seed systems provide most seed used by farmers and are increasingly being used to deliver MVs to farmers

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

Nearly all farmers in developing countries depend largely on their own seed or seed obtained from relatives or the market for planting (Almekinders and Louwaars, 1999; Tripp, 2001). Furthermore most MVs in developing countries originate from public sector organisations and the only crop where commercial companies have had a large impact – and have networks capable of delivering seed - is that of hybrid maize (Morris, 2002). Therefore local seed systems are very important, especially in times of drought or civil unrest. These systems are also very robust and support the local economy. Relief agencies promote these systems by using seed vouchers (Sperling et al., 2004). One advantage of participatory approaches is that they use these systems to spread seed, either deliberately or inadvertently. Studies in India have shown that seed can move 100s of kilometers through these informal systems, and that entrepreneurs quickly act to meet demand for seed (Witcombe et al., 1999)

3.2.3.3 Learning and capacity strengthening

3.2.3.3.1 Extension and training

Education and training are widely acknowledged as contributors to national economic well-being and growth.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5, 6	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 is playing a critical role in the transfer of agricultural technology. Agricultural centers of excellence are yielding new technologies, and agricultural education is assisting with technology transfer activities by being a part of interdisciplinary research teams. The increasing role of informal mechanisms for information sharing has been recognized as farmer-to-farmer models of agricultural development (Eveleens et al., 1996).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 4, 5	B	0 to +3	G	Widespread applicability

Formal capacity development in developing countries needs to go beyond predominantly disciplinary expertise and produce broad-based professionals that recognize the ‘systems’ nature of innovation and change, and its relationships with society. As sociological, cultural, agricultural and environmental issues are more and more inter-linked, the increasing multiplicity of stakeholders, with differing and often conflicting land use representations and strategies, the complexity of the combined impacts of these strategies on the shared resources, underlines the need for innovative methods and tools to support their coordination, mediation and negotiation processes aiming at an improved, more decentralized and integrated natural resources management (D’Aquino et al., 2003). The combined use of modelling and role-playing games for helping professionals and stakeholders to understand these interactions dynamics could be an option (Antona et al., 2003)

Most management changes in farm businesses make use of several learning sources.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	0 to +3	G	Wide applicability

Informal learning sources in the form of experts, other farmers and formal training activities were frequently used as learning sources for change and more than one member of the farm management team was involved in almost all of the learning-for-change processes studied by Kilpatrick *et al.*, (1999). Learning that takes place in groups or communities also plays an important role in modifying farmers’ values by increasing their otherwise limited opportunities for interactive learning. The opportunity to alter values and attitudes in these ways increases the probability of a change to practice (Kilpatrick, 2000). In short, there has been an increasing recognition that farming does not take place in a social or cultural vacuum. It is a social activity (Dunn et al. In press). In recent years, agriculture has experienced an increasing interest in learning, and participation in activities (Kilpatrick et al., 1999).

Access to agricultural information, especially about technologies, policies and markets, has been shown to play an important role in sustainable agricultural development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5, 6	B	0 to +3	G	Wide applicability

Levels of Government funding to agricultural extension services have declined in many developing countries. Approaches that emphasise the broad-based, multi-stakeholder character of innovation and communication are highly relevant in this context. Civil society organizations and national and international NGOs, have a growing track record of active participation in agricultural research and development. This supports local systems that enhance the capacity to innovate and apply knowledge. There is general consensus about the importance of private sector participation; however, the constraints to this occurring are increasingly being recognised. Issues of incentives and roles for different stakeholders remain to be resolved. Case studies from Southern Africa of private sector-led development showed that private firms have significant potential to improve smallholder crop management practices and productivity, by supplying farmers with new cultivars, nutrients, pesticides, farm equipment, information, capital, and other services, but that market, institutional, government, and policy failures currently limit expanded private sector participation (Rusike and Dimes, 2004.

Agricultural extension is recognised as an essential mechanism for delivering information and advice as an "input" into modem farming.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5. 6	A	0 to +5	G	Worldwide

Since commercial farmers can derive direct financial benefits from these inputs, there is a trend towards the privatization of the extension organizations, often as parastatal or quasigovernmental agencies, with farmers being required to pay for services which they had previously received free of charge. This trend is strong in the North, and there are examples of it beginning in the South (FAO, 1995; Jones, 1990). Currently, countries in Africa are searching for participatory, pluralistic, decentralized approaches to service provision to small-scale farmers. There is debate by practitioners on extension privatization, contracting extension, farmer participation and other empowerment models. Participatory extension approaches such as the Farmer Field Schools (FFS) are emerging methodologies for technology validation and dissemination in Africa This means learning to interact closely with social groups and communities (Asiabaka, 2003; AGRITEX, 1998).

Lack of education/extension is a constraint to technology transfer, trade and marketing, and business development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1,2, 3, 4, 5, 6	A	-5 to 0	G	Worldwide

Many developing countries have large numbers of illiterate people in their populations. This is a severe constraint to the development of all areas of economic and social growth. Adult education programs require new approaches to training and extension, which still need to be fully developed. Juma (2006) has urged African governments to rehabilitate university infrastructures, particularly information and communication facilities; to generate new institutional designs linking institutions of higher education to hospitals, communities, research stations, and the private sector; and to re-design curricula and pedagogy to encourage creativity, enquiry and entrepreneurship and experiential learning.

Gender imbalances in agricultural extension systems limit women's access to information.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	-2 to +4	G	Worldwide

There is a severe gender imbalance in agricultural extension services. Women constitute only 12.3% of extension workers in Africa (UNDP, 1995). Gender issues are very important in design of programs and to a great extent determine the success or failure of the training/extension activity. Other social groups (disabled, HIV orphans, youth, etc.) are also often ignored or marginalized in the design of training program for adaptation of AKST. These groups constitute large parts of the population in some societies. The number of women seeking higher education in agriculture is on the rise in some developing countries, although female enrolment rates remain considerably lower than males (FAO, 1995). Some improvements have occurred since the 1980s and women appear to be employed in larger numbers in national agricultural institutions. However, men still comprise the overwhelming majority 'of those employed, especially occupying high managerial and decision-making positions (FAO, 1995).

Currently, in most developing countries there are insufficient numbers of trainers in rural communities to promote important participatory approaches to rural development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	B	-4 to -2	G	Widespread in developing countries

Overcoming this shortage will require a chain of training courses, with the Training of Trainers as the first step. The World Agroforestry Centre is an example of one international institution which is attempting to provide training to farmers, through mentorship programs with Farmer Training Schools, scholarships for womens' education, support of young professionals in partner countries and the development of Networks for Agroforestry Education, eg. ANAFE (124 institutions in 34 African countries) and SEANAFE (70 institutions in 5 South East Asian countries) (Temu et al., 2001). Agencies such as the International Foundation for Science (www.ifs.se), and the Australian Centre for International Agricultural Research (www.aciar.gov.au), additionally provide funds to allow new graduates trained overseas to get re-established in the home countries.

Farmer Training Schools bring farmers together to learn special skills.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	B	0 to +3	R	Wide applicability

For example in West Africa, the Sustainable Tree Crops Program is training groups Master Trainers, who then train 'Trainers of Trainers', and eventually groups of farmers in the skills needed to grow cocoa sustainably. This includes such things as: tree pruning, good agricultural practices, spraying crops safely, issues with child labour, etc. (STCP Newsletter, 2003).

In Africa expenditire related to agriculture and extension fell by 50% for some time, reducing not only extension coverage but also the quality.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5, 6	B	-3 to 0	R	Africa

In the past extension services were key in assisting the green revolution by promoting new technologies to improve crop and livestock productivity. Public funds financed such an extension system through national resources or through international cooperation funds in the poorest countries. The Training and Visit method (Benor 1984) developed by World Bank projects operated in 50 countries through loans devoted to reinforce national public structures. There continues to be a shortage of trained manpower in fields related to agriculture despite the progress that has been made in the last three decades. Today, two out of three farmers in Africa have no contact with extension services. In developing countries, 6% of extension agent's time and resources are devoted to large commercial farmers; 26% to smaller commercial farmers; 24% to smallholder farmers; and 6% to rural women (FAO, 1990). The literacy and training levels of the extension workers are not satisfactory in relation to the challenges. Worldwide the public sector plays a dominant role in the provision of agricultural extension and services (Axinn and Thorat, 1972; Lees, 1990; Swanson, Bentz and Sofranko, 1997). Critics of public extension claim that its services need to be reoriented, redirected and revitalised (Rivera and Cary, 1997). On one hand the states' withdrawal with public funds implied a strong reduction of the public extension services. On the other hand, the poor efficiency of traditional extension system (Anderson and al., 2004) undermined interest in such an approach. Since the 90s there have been many initiatives to deliver efficient services. The inclusion of the private sector to ensure competition is gaining credence as one solution, especially with regard to agricultural input-supply firms (Davidson et al, 2001). The private extension sector can deliver adequate services to commercial farmers and large scale-farmers. In the poorest regions, NGOs strengthen their extension activities with farmers who are not able to pay for the services and participatory approaches are applied. In other cases, new experiences are developed to promote extension systems based on farmers' capacity building mechanisms and appropriate decision making tools at farm level through farmers' organizations empowerment or through private-public partnership (Faure et al, 2004). Promising results are evident, but there still remain crucial problems related to (i) the need for strong farmers' governance to monitor and assess extension activities and (ii) sustainable funding with fair cost sharing between the stakeholders including the State, private sector, farmers' organizations, and farmers.

Extension services are no longer viewed as exclusively providing information in agricultural methods.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	B	-2 to +4	G	Wide applicability

Target groups are not restricted only to farmers, but cover a larger audience of women and rural youths. Increasingly environmental and sustainable development issues are being incorporated into agricultural education and extension programmes (FAO, 1995).

3.2.3.3.2 Information management

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	-4 to +4	G	Worldwide

Problems of information access affect producers in low-income countries, although commercial operations could benefit. Inevitably, issues of equitable access and dissemination will arise as marginalized populations are bypassed (FAO, 2002). Farmers have an array of informal and formal sources from which they seek and obtain information (Olowu and Igodan 1989, Nwachukwu and Akinbode 1989, Ogunwale and Laogun 1997). Village heads and NGO agents are moderately used while other sources such as research institutes, extension leaflets, television, mobile films, and farmers' resource centers are sparingly used (IITA 2005). Information and knowledge about new technologies and markets have been found to diffuse through social networks of friends, relatives and acquaintances (Barr 2002; Fafchamps and Minten 2001; Collier 1998; Conley and Udry 2001).

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	-3 to +4	G	Worldwide

Information and Computer Technology (ICT) is revolutionizing agricultural information dissemination (Boselie 2003). For example, rural development in the United States is fostered by organisations, including industry associations, which serve as networks for information exchange, providers of services and facilitate cooperation among producers, processors, transporters and marketers (Galston and Baehler, 1995). Mills and Winter (cited in Cerf et al., 2001) compare two institutional frameworks in British agriculture and show the greater effectiveness of locally-based, decentralised networked institutions with local involvement. There have been enormous advances in information technology and the task of managing and disseminating information in a digital environment has become increasingly complex. Limitations in information management to date include decentralised production, quality management, income generation, and local capacity strengthening. The challenge is how to improve accessibility of science and technology information about agricultural development and food security. This challenge is multidimensional, covering language issues as well as those of intellectual property and physical accessibility

Agricultural thesauri like AGROVOC are playing a substantial role in helping information managers and information users in document indexing and information retrieval tasks.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	0 to +3	G	Wide applicability

With the advancement of the web, information management tasks require still more versatile and flexible tools that facilitate the task of systematically and logically organizing and finding information on the web. "Information Organisation" problem faced by Information Managers and the 'Information Retrieval' problem faced by Information users (http://www.fao.org/agrovoc/). At present, most information management tasks are performed by humans, with little automation, these include cataloguing and indexing tasks.

With the advent of the Internet in the 1990s, there have been enormous advances in information technology, and the task of managing and disseminating information in a digital environment has become increasingly complex.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	0 to +4	G	Worldwide

Although much has already been done in the development of information management, the outreach within the agriculture sector is still limited particularly in developing countries. With respect to Information Management, there are limitations of appropriate methods and tools for agricultural information management, and capacity to manage agricultural information effectively. International organizations such as FAO have responded to requests 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).

3.2.3.4 Gender

Women play a substantial role in food production worldwide.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	-3 to +3	G	Worldwide

In Asia and Africa women produce over 60% and 70% of the food respectively, but because of inadequate measurement, their work is underestimated and does not appear in the national accounts for the Gross National Product (GNP). Nor are women integrated in agricultural education or training, and in 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. FAO (www.fao.org/gender) recognizes that the empowerment of women is key to raising levels of nutrition, improving the production and distribution of food and agricultural products and enhancing the living conditions of rural populations (UNIFEM, 1994), and thus to the achievement of World Food Summit (1996) goal of halving the number of hungry people in the world by 2015.

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
1, 2, 3, 4, 5, 6	B	0 to +3	G	Wide applicability

Resource poor-resource women farmers' substantial roles are often marginalized and undervalued in agricultural analyses and policies. For example, agricultural programmes designed to increase women's income and household nutrition must 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 favours males, which can give rise to micronutrient deficiencies in women and children which 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.) The benefits from an agricultural programme in Bangladesh targeted at improving women's household income were greater for fish production using a group approach, than for vegetable production carried out by individuals in their homesteads. 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. The lesson is that income-generating programs targeting women as individuals must also provide alternative sources of social support in order to achieve their gender-related objectives.

Programmes to promote commercial crop production and market access need to address men's and women's access to finance, inputs, information and market linkages.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 5	B	0 to +2	R	Wide applicability

For social 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 labour or control their income (references). One of the reasons that the participatory domestication of indigenous fruits and nuts has been successful in West Africa is the coincidence of fruiting of some of the priority species producing marketable fruits, with the need to pay school fees and buy school uniforms (Schreckenberg et al., 2002, 2006).

The feminization of agriculture places a burden on women who have few rights

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-3 to 0	G	Especially in the tropics

Rural women produce between 60-80% of the food in most developing countries (FAO, 2004). Progress on the advancement of the status of rural women has not been systematic enough 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 areas has thrown into prominence 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 go to the city, or neighboring rural areas, in search of paid jobs leaving the women to do the farming and provide food for the family (Song, 1999; FAO, 1998).

There is gender inequality in land ownership and access to agricultural resources.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-2 to +3	G	Common occurrence

Women's contribution to food security is not reflected in ownership and access to services. 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 credit provided to their male counterparts). Rural women also have less access than men to credit, which limits their ability to purchase seeds, fertilizers and other inputs needed to adopt new farming techniques. Although this is improving slowly due to the increase in special programmes and funds created to address women's particular needs, access to land continues to pose problems for rural women in most countries. In Africa, women tend to be unpaid labourers on their husbands' land and 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 might not survive the death of their spouse (Bullock, 1993; p45). 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, 1993: p25) Traditionally, irrigation agencies have tended to exclude women from access to water— for example, by requiring land titles to obtain access to irrigation water (Koppen, 2002). Explicitly targeting women farmers in water development schemes and giving them a voice in water management is an essential ingredient for the success of poverty alleviation programs. To date, labour-saving technologies specifically developed to make women's work more effective in crop and livestock production have not been adequately introduced**.** 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 (FAO, 2001). In the short-term, making more material resources available to women for land, credit and technology at micro level is mostly a question of putting existing policies into practice. At the macro-level, however, changes are coming slowly and will depend on a more favourable gender balance at all levels of the power structure (Commonwealth Secretariat, 2000). In Africa, the creation of national women's institutions was a critically important step in ensuring that womens' needs and constraints were put on the national policy agenda. (FAO, 1990b) The introduction of conventions, agreements, new legislation, policies and programmes has been a critical step towards increasing women's access to and control over productive resources. However, most often, rural people remain unaware of women's legal rights or 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 their 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 have had less access to formal information and communication systems associated with agricultural research and extension.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	B	-3 to 0	G	Wide applicability

Worldwide, there are relatively few professional women in agriculture. In Africa, men continue to dominate the agricultural disciplines in secondary schools, they constitute the majority of the extension department personnel (with the exception of home economics), and are the primary recipients of extension services. Men's enrolment is also increasing in agricultural disciplines at the university level (FAO, 1990b; 2003). Only 15% of the world's agricultural extension agents are women (FAO, 2004. Recent research has shown that only one-tenth of the scientists working in the CGIAR system are women (Rathgeber, 2002) and women rarely select agricultural courses in universities (Rathgeber, 2003).

3.2.4 Innovation systems, policy and stakeholder partnerships

The interactions between AKST and the coordination processes among stakeholders are important for sustainability. AKST influences market and/or policy mechanisms that subsequently allow the design of new and more appropriate coordination mechanisms. This analysis examines how:

- the knowledge of innovation systems have eased or contrarily hampered the adoption of invention and change It identifies the different factors that have influenced adoption, and how they can improve innovation.
- knowledge systems (notably economic theory knowledge, have shaped the current systems. It identifies the emergence of new policies to fill in legal gaps or to take into account new approaches, notably to sustainable development.
- globalization and liberalization, based on neo-classical economic theory, have radically changed agricultural production and trading systems.
- new stakeholders have emerged, used and adapted local and global forms of AKST
- the dynamics of innovation vary at local and global levels.

3.2.4.1 Innovation systems and AKST

3.2.4.1.1 The efficiency of research producing development-oriented AKST

It is recognized that investment in agricultural research has been highly cost effective and has benefited local economies

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3	B	+2 to +4	G	Wide applicability

Positive gains in productivity have been driven by investment in research, notably in the CGIAR system (Brossier, 2001). Benefit-cost ratios for research of between 2 (significantly demonstrated and empirically attributed) and 17 (plausible, extrapolated to 2011) have been achieved by CGIAR research (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 $30 billion [at 1990 values] (Evenson and Gollin, 2003b; Raitzer, 2003; Hossain et al., 2003; Heisey et al., 2002; Lantican et al., 2005). As a measure of this success, the CGIAR has estimated that 30 years of agricultural research on seven major crops has improved yield gains so much that this has 'avoided' the clearance of 230-340M ha of forests and grasslands (FAO, 2003). A cost/benefit analysis by ACIAR (Raitzer and Lindner, 2005) found that of their research projects those involving forestry/agroforestry had the greatest plausible benefits (42.9%). There is also good evidence that increases in total factor productivity, which contribute to increased output, are always associated with investment in research (Pingali and Heisey, 1999).

Science and technology generated by agricultural research and development institutes has not always been translated into economically useful, socially-appropriate and environmentally-desirable applications.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	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). Consequently, in recent years there has been a growing appreciation of the need for new AKST to meet sustainability criteria, taking into account the economic, social and environmental pressures so that new approaches, methods and techniques are effective (Engel et al., 1988) and meet the Millennium Development Goals (e.g. Garrity, 2004). Additionally, increases of agricultural production may be achieved through global promotion and financing in related areas of importance, such as improvements in environmental sustainability and public health (UN, 2004). This has required major advances in our ability to analyze, understand and predict the behavior of the complex systems within which we live (Hasan and Abdul Rahman, 2005). It has also depended on participatory learning and action in developing countries (Haverkort et al., 1991; Okali et al., 1994; Scoones and Thompson, 1994; Cerf et al., 2000; Roling and Wagemakers, 1998). Evidence suggests that in this way future actions can be appropriate to the needs, interests and capabilities of the stakeholders and, through collaboration, can be translated into new products and processes that result in social, economic and environmental benefits.

Agricultural science and technology has not succeeded in increasing agricultural productivity in Africa to its full potential.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3	B	-2 to -4	R	Especially Africa

In many African countries, poverty, low agricultural productivity and environmental degradation have been found to be inextricably linked, as poor farmers mine soil fertility and deplete other available resources in an effort to survive (World Bank, 2004). Recent evidence suggests that solving this problem will depend on an integrated approach to resolving these complex socio-economic and biophysical constraints to agricultural development (Izac and Sanchez, 2001). Agroforestry provides a relevant example as it is an integrated, grassroots, multi-disciplinary approach to natural resources management, which meets many of the needs of resource-poor rural communities (Leakey, 2001 a/b).

3.2.4.1.2 From AKST production to AKST adoption

Analyses reveal that the Green Revolution succeeded only when the dissemination of AKST was accompanied by policy reforms.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 to +2	R	Wide applicability

Policy reform was particularly important for the successful adoption of Green Revolution rice production technologies in Asia. Countries, such as Indonesia, that implemented relevant price, input, credit, extension and irrigation policies to facilitate the dissemination of the cultivation of potentially high-yielding, dwarf varieties, managed to increase physical yields by a factor of four or five per area unit, as well as achieving very significant increases in labour productivity and rural employment (Trebuil and Hossain, 2004.) In Vietnam, the implementation of similar policies in 1988 increased rice production in the Mekong delta (Le Coq and Trebuil, 2005).

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

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

Exclusion and marginalisation processes such as poverty, hunger or rural migration, have often occurred because of differences in peoples capacity to make use of knowledge and technology and access resources. Other factors have included the impacts of new technologies to justify trade rules and regulations or property rights, etc. For example, the implementation of new technology represents differentiation factors that might exclude farmers and their families from production and marketing. Target-oriented programs, such as those addressing the Millennium Development Goals, overcome this problem by focusing on particular indicators of success and the specific roles of AKST within the innovation system. This approach also addresses this problem, by matching technology development with institutional arrangements. This enhances the capacity of the agricultural sector to prevent conflict and crisis and to contribute to the transformation of society and global development.

Scaling up the adoption of new technologies requires much more than just their development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
5	C	-2 to +2	G	Wide applicability

Adoption and impact of new agricultural techniques are negatively affected by overlooking the human/cultural issues, ignoring local knowledge systems and reducing the solution of agricultural problems to pure technology (Feder et al., 1985) - to be completed.

Acceptance of technical innovations is affected by the efficiency of the coordination activities between the actors, especially for the supply of local or regional urban markets.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3	B	-2 to +4	G	Wide applicability

The coordination among different stakeholders involved in the technical innovation process, e.g. farmers, extension, research, traders, etc., is central to successful adoption (Moustier et al. 2005) Knowledge and methodologies crossing systematic analyses and the contributions of new institutional economics help accelerate innovation (Griffon, 1994). Such approaches have been found to contribute by connecting experimental and non-experimental disciplines, basic and applied research, and especially, technical, organizational, and economic variables, so increasing investment efficiency. It has been found that the efficiency of agricultural innovation is increased when technological changes properly value the existing indigenous production systems and use of local resources: biological, economic (Temple, 2006). This illustrates that models of agricultural intensification require more than technological innovation.

Integrated Natural Resources Management currently acknowledges that technical and institutional innovation processes are generated and disseminated through flexible and active networks.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	-2 to +4	G	Wide applicability

INRM initiatives involve a lead role for farmers and local knowledge through a collective learning process, involving continuous dialogue, negotiation and deliberation amongst stakeholders – particularly the researchers (Röling, 1996; Sayer and Campbell 2001). Failure to recognize this is leads to poor adoption potential of the research outputs (reference). These failures of the organization of agricultural research and extension are clearly demonstrated when there is little incentive to interact with the farmers and the private sector (Röling 1988). International and national research institutions and specific public agencies have not paid enough attention to analyzing how knowledge moves between researchers and end users (reference?).

Biotechnological innovations are experiencing adoption difficulties, as illustrated by their limited commercialization.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	-2 to -4	G	Wide applicability

Increasingly, new crop trials include ‘genetic modifications’, but public acceptance of this technology is limited, especially in Europe (reference). The European Union has moved from a situation of no regulation on agricultural biotechnology in the mid-1980s to very stringent regulations on the approval of GM-crops and GM-foods, with increasingly stringent and harmonized labeling requirements. As a result, very few GM-crops and GM-foods have been approved for commercialization, and the number of field trials has remained low. Consequently, virtually no GM-crops are commercially grown in the EU. The strict labeling laws have resulted on very few GM-products being sold on the European market. This can be seen as an indication that consumer demand for GM-products is almost non-existent (Bernauer 2002). On the other hand the situation is not absolute, and recent reports indicate that some 75% of cotton imported into the EU today is from GM varieties, coming mainly from USA and China (reference?). It is reported that 15 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) (reference?).

Poor adoption due to fears about Genetically Modified Crops have had some serious economic impacts.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	B	-3 to -4	G	Wide applicability

Canadian farmers have lost the market for $300 million of canola (oilseed rape) to GMO-free markets in Europe, after adopting GM varieties (Shiva et al., 2004), while the discovery of Bt-corn grown in USA for animal feed in corn for human consumption led to product recalls estimated at over $1 billion (Shiva et al., 2004). Maize exports from US 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 (Centre for Food Safety, 2006).

The marketing of products from a wide range of species raises ethical issues about the commercialization of biodiversity.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	C	-3 to +3	G	Wide applicability

The Convention on Biological Diversity (CBD: www. biodiv.org) 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 has 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. 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 when engaging in 'biodiscovery' and 'bioprospecting' (Laird, 2002), and support and enhance genetic diversity (Almekinders and de Boef, 2000).

3.2.4.1.3 Necessity to connect organizations involved in components of land use

At the national and international level, government ministries and international agencies responsible for agriculture, livestock, fisheries and food crops are typically separate and in competition for resources, power, etc.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	C	-3 to 0	G	Wide applicability

This separation of ministries in many countries around the world has created competition between the various 'sub-sectors' of agriculture, with policies and laws fixing trade-offs that become decreasingly desirable as circumstances change: for example, promoting forest removal for farmers to secure agricultural land tenure and grants (Angelsen and Kaimowitz, 2001). The undesirable separation of these institutions also means that synergies are not sought. For example, when farming KST is able to improve crop productivity in traditional, settled farming systems with adequate infrastructure and employment, it can indeed 'save' natural forests from clearance (Angelsen and Kaimowitz, 2001), and new initiatives are now seeking better recognition of forest benefits, especially the ecosystem services (eg. Ecoagriculture: McNeely and Scherr, 2003, and landcare: Buck et al.,????). This disconnect also occurs at the international level, eg. World Commission on Forests and Sustainable

Development (1999), and the UN Forum on Forests, Inter Academy Council Report on African Agriculture (2004).

At the national and international level, there are disconnections between the organizations responsible for the environment and conservation and those that support and regulate production of agricultural crops, forestry, livestock and fisheries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	-3 to 0	G	Wide applicability

The possibilities of creating synergies between increased production and IAASTD's development and sustainability goals are limited by this disconnect between agriculture and the environment. Perhaps, therefore, it is not surprising that the concepts of sustainable land use are 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 influencing both environmental authorities and land use planning authorities at least as much as agricultural authorities and may be promoted by the former as instruments for achieving environmental policy goals (Abbott et al., 1999; Dalal-Clayton and Bass, 2002; Dalal-Cayton et al., 2003).

In recent years the interaction between international research centers of the CGIAR and the National Agricultural Systems has improved

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	0 to +2	G	Wide applicability

Many CG Centres now engage in active collaboration with NARs, and through this have a better understanding of the needs of local farmers. However, the relationship between international public goods research and national research priorities are not always clear (reference?). With the advent of INRM research in the development of AKST for more environmentally and socially sustainable approaches to agriculture, the two-way flow of information in this relationship will be even more important. Currently this flow is also lacking between the biotechnology industries and INRM research and practitioners in developing countries.

3.2.4.2 The problem solving cycle, adoption and policy making

3.2.4.2.1 Assessment and recent evolution of AKST and AKST policies

The agricultural crisis is illustrated by Africa becoming progressively a net importer of agricultural products.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	-3 to +3	R	Especially Africa

The "Green Revolution" research paradigm yielded large production gains in few export commodity crops, basic grains and livestock, at the expense of soil degradation, irrigation-induced water salinity, biodiversity, and non-cultivated land (Pingali and Rosegrant, 1994). Moreover, the gains rarely benefited the poor and marginal farmers, and they were confined to areas of high agricultural potential (Sayer and Campbell, 2001). In developed countries and mainly in Europe, the intensive agricultural development led to over supply, sanitary problems affecting livestock production and ecological issues, while the concentration of production no longer allowed maintaining rural areas.

Sustainable agricultural development involves environmental and social functions

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	B	0 to +3	G	Wide applicability

Since the 1990's, various initiatives have attempted to integrate social and environmental functions with those of production to promote multifunctional agriculture by designing policies and incentives for increased net collective benefits of agriculture as recommended by the "doubly green revolution" approach (Griffon and Weber, 1996; CGIAR/TAC, 1998; OECD, 2001), together with economical growth (Rio, 1992). Attempts have been made to identify under what conditions alternative approaches would allow agricultural development to be based on ecosystem-friendly activities by promoting of systems variability, rather than attempting to control the environment (Griffon and Weber, 1998) i.e. substituted a 'resource-saving' growth for a 'rent-for-surplus' growth (Plateau, 2000). In both developing and developed countries, the concern is to recognize that agriculture has also collective environmental and social functions and underpinnings.

Agricultural policies have given inadequate attention in the past to the livelihood needs of small-scale farmers and the rural poor.

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

Agricultural policy over the last 50 years has focused on the production of staple foods and meeting the immediate food needs to avoid starvation in the growing world population (reference?), rather than targeting the multiple needs of the rural population. This situation has changed over the last 10 years with the development of a livelihoods focus in rural development projects (Carney, 1998). Nevertheless, 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 smallholder farmers (reference?). The stronger livelihood focus is based on diversified farming systems, often mimicking some of the innovative developments which and offering good alternatives to slash-and-burn (Palm et al., 2005a). These typically provide radical improvements in farmer livelihoods (Vosti et al., 2005) and environmental benefits (Tomich et al., 2005).

3.2.4.2.2 AKST to address the new environmental and social concerns, water management, biosafety regulations, intellectual property rights.

During the twentieth century, governments dramatically expanded their roles in water management.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	-2 to +2	G	Wide applicability

Large dams, reservoirs and irrigation systems have typically been built by government agencies, which operated them for economic development (including agriculture), urbanization, power generation, rather than for sustainable development. The rules and procedures of such projects play a major role in determining who received water. Agriculture is by far the largest sector of water use in most countries, but its share of freshwater resource use decreased with increased industrialization (World Resources Institute, 1997 in: de Sherbinin and Dompka, 1998, UN and WMO, 1997). Agricultural users are the most likely to have some system of traditional water rights, which were frequently overlooked by the water management agency. Communities of water users have, therefore, faced numerous challenges in gaining equitable and sustainable access to, and allocations of, water (Bruns and Meinzen-Dick, 2000; Meinzen-Dick and Pradhan, 2002). In recent years, Water User Associations have become a more common way of managing water delivery (Abernethy, 2003), in which the equitable distribution of irrigation water, for example, is achieved by allowing the same duration of water delivery to each irrigated hectare, or the same quantity of water to each household (Shlager, 2003). In South Africa, the National Water Act promotes integrated and decentralized water resources management (Hamann and O'Riordan, 2000; Perret, 2002) under a new institutional arrangement which promotes negotiation and discussion processes conducted with local stakeholders towards a common vision about the use and management of their resource (ComMod Group, 2004).

Recently water allocation has received considerable attention by the scientific community.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	B	0 to +2	G	Wide applicability

Optimization economic models for decision-support have dominated the international literature on water allocation among competing sectors (Firoozi and Merrifield, 2003; Weber, 2001; Salman et al., 2001). But recently there have been an increasing number of studies adopting simulation and multi-objective frameworks. For example, Bielsa and Duarte (2001) developed an economic model for allocating water between two competing sectors, namely irrigation and hydropower in North Eastern Spain, while Reca et al. (2001) developed an economic optimization model for water resources planning in deficit irrigation systems. Multi-objective optimization models for water planning have also been used in the Aral Sea Basin, because of the uncertain nature of its water availability (McKinney and Cai, 2002). Now simple interactive, integrated water allocation model (IWAM), have been developed to assist the planners and decision makers to optimally allocate limited water 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 three user sectors based on flow and shortage rights, consumptive rights and irrigation efficiencies (Green and Hamilton, 2000).

Intellectual property rights regulatory frameworks are becoming critical to the enhancement of natural resources and the protection of indigenous farmers' rights to genetic resources and community innovations.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	B	0 to +3	G	Wide applicability

The objectives of the International Treaty on Plant Genetic Resources for Food and Agriculture are 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, in harmony with the Convention on Biological Diversity (UNEP, 1993), for sustainable agriculture and food security (FAO, 2001). This 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” (Célarier and Marie-Vivien 2001; Feyt, 2001; Mortureux, 1999). The Treaty includes a strategy to mobilise funding for priority activities in particular in developing and transitional countries, taking into account the Leipzig Global Plan of Action (FAO, 1996) for the realisation of Farmers’ Rights by national governments. It was adopted by 150 countries at Leipzig in 1996 and subsequently endorsed by the FAO Conference and the Conference of Parties of the Convention on Biological Diversity (FAO, 1996).

Indigenous resource-poor farming communities are the creators, custodians and continuing innovators of biological knowledge and resources.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 5	A	0 to +3	G	Wide applicability

Our foods originate from a few improved, high yield varieties of a very limited number of species (CIP-UPWARD, 2003). Agricultural ecosystems are rarely considered as producers of diversity, but in fact they hold the key to the future, and consequently, agro-biodiversity requires active and sustained human intervention and conservation (Brookfield, 2001; Brookfield et al., 2002; Brush, 1999; Wood and Lenne, 1999). Many food plants are the result of the selections and improvements made by farmers (Mazoyer and Roudart, 2002) and this domestication is an important source of germplasm for future selection and breeding. In addition, the wild relatives of many present and future food plants are concentrated in unique and often remote regions of the world. These "centres of diversity" largely remain situated in developing countries where traditional agriculture allowed the conservation of diverse cultivated environments. This germplasm is the raw material for future agricultural production and are a reservoir of genetic adaptability that can withstand economic and environmental change (Collins and Qualset, 1999; Flora, 2001) if the diversity found within and between species, and within ecosystems, is protected.

There are serious gaps and inefficiencies in the conservation and implementation of Plant Genetic Resources for Food and Agriculture policies .

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	C	-3 to +3	G	Wide applicability

There are many issues associated with the development of Intellectual Property Rights frameworks at international and national scales, as none of the systems (patents, trade marks, contracts, GI, varieties) allow a complete protection of farmers’ rights. 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. In Europe and USA, the role development of patent systems and plant breeders’ rights is genuinely fostering innovation and conferring benefits to innovators, while also protecting genetic resources. However, in developing countries the theory is rarely put into practice by small-scale rural entrepreneurs, instead international agencies like FAO and the CGIAR provide protection for the genetic resources of staple food crops improved by CG Centres through public-funded research (Jarvis et al., 2000; Frison et al., 1998; Sauvé and Watts, 2003). Currently much international activity by NGOs and farmers' 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 minimize the risks from biotechnology governments are developing 'National Biosafety Frameworks'

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
2, 3, 4, 5	C	Not yet known	G	Worldwide

Governments are developing 'National Biosafety Frameworks' to support the application and use of modern biotechnology in accordance with national policies, laws and international obligations, in particular the Cartegena Protocol on Biosafety (Secretariat of the Convention on Biological Diversity, 2000). What is paramount is for countries to have capacity and mechanisms to make informed decisions as they accept or reject products of modern biotechnology (Per-pinstup-Andersen and Abbe Schioler 2001). By 2006, eighty developing countries had developed their National Biosafety Frameworks with good capacity for biosafety assessment under UNEP-GEF support project (http://www.unep.ch/biosafety/news.htm) A comprehensive communication strategy is also needed to create awareness among all stakeholders and allow appropriate dissemination of biotechnology products. When policy-makers receive mixed messages, the formulation of policies and regulations related to biotechnological applications is delayed (Kisamba Mugerwa, 2005).

Policies and regulatory procedures are vital for the successful implementation of biotechnology for agricultural development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	-2 to 0	G	Wide applicability

The lack of policy and regulation related to agricultural biotechnology in many countries has led to differences in public understanding and confidence in the technology. The available knowledge has not been adequately analyzed to address the concerns of different institutions and stakeholders with different objectives. A comprehensive communication strategy is needed to create awareness among all stakeholders and so allow appropriate dissemination of biotechnology products. When policy-makers receive mixed messages, the formulation of policies and regulations related to biotechnological applications is delayed and/or misinformed (Kisamba Mugerwa, 2005).

3.2.4.3 Understanding market liberalization and its effects on development and contributing to new regulation patterns

3.2.4.3.1 Globalization and emergence of new regulation patterns and organizations

Globalization has been one of the strongest forces in international development during past decades and has dramatically and definitively shaped AKST in the 20th Century, notably through economic and trade policies and regulations.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	B	-3 to +3	G	Wide applicability

International trade agreements and institutions, along with multinational corporations, have been major drivers, both directly and indirectly, in determining food production and food policies (reference?). The economic globalization model promoted by these institutions is characterized by intense import-export based industrial food production systems directing AKST away from systems of food grown locally primarily for local consumption to foods being grown for export (reference?). The positive impacts of globalization have been greatest in developed countries (reference) while in developing countries there have been both positive and negative impacts (references).

The globalization process has been supported by international and regional trade policies (such as WTO or NAFTA), as well as by the policy recommendations (structural adjustment programs) made by international institutions (World Bank and IMF).

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	A	-2 to +2	G	Wide applicability

There are links between global trade and economic agreements and institutions, such as the WTO/IMF, bi-lateral agreements, and domestic and regional agricultural policies, technologies, R&D, natural resources. AKST played a role in this process, particularly neo-classical economic theory. Assessment of the impact of these policies demonstrates a growing concern in terms of sustainability (Stiglitz, 2002).

Recently the concept of 'Enlightened Globalization' has been enunciated, aimed at encouraging developed countries to work more effectively to benefit the poor, the global environment and the spread of democracy.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	D	Not yet known	G	Wide applicability

Sachs (2005) has proposed that to end poverty, there is a need to rethink the concept of Globalization in a way "that addresses the needs of the poorest of the poor, the global environment, and the spread of democracy". He describes this as "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 would also help poor countries to gain access to the markets of richer countries, instead of blocking trade and investment.

Before the 1980's, international institutions and development thinking was strongly influenced by the findings of agricultural economics research.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	D	-2 to +3	G	Wide applicability

From the 1930's, a time when agricultural markets instability was identified as a key determinant of economic collapse, real wage fall and unemployment, the functioning of markets for agricultural products has been influenced by the findings of Ezekiel, Keynes and Schultz. Agricultural economic research on the causes and consequences market instability on people and national economies hence shaped the post-war development policies up to the time when many countries were gaining Independence. These policies led to new institutional schemes to address development issues through the creation of UNCTAD and the formulation of special arrangements under GATT in the 1970s.

Recently, the development micro-economics, agricultural economics of international markets have called for *sui generis* policies.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	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 (Banerjee and Duflo, 2005: Sadoulet and de Janvry, 2001) which experimentally assessed the best way to draw people out of poverty, and provided powerful insights on development policies targeting education and health). 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 (Binswanger, 1981; Newberry and Stiglitz, 1979; Rothschild and Stiglitz, 1976; Stiglitz, 1987). In trade economics, work on the implications of uninsured agricultural risk on development and growth is now providing valuable information and tools to understand the effects of trade openness on countries and households (Boussard et al., 2006). In the second approach to international markets research, agricultural economics continues to explore the value and power distribution along commodity chains (Gibbons, 2005; Gereffi, 1994; Daviron, 2005), to determine how new patterns of labour organisation throughout the chain impact upon its overall function – and notably impact on farmers' income.

3.2.4.3.2. International trade policies: reducing AKST to rules and standards

Coordination modes for the development of international policies, incarnated by the WTO, have strongly influenced global AKST, and in particular the agricultural and food policies.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	B	?	G	Wide applicability

Trade policies have ……. (Krasner, 1983), this having positive/negative? impacts on agricultural production, farmers' livelihoods, etc. (Friedmann, 1982; Hopkins and Puchala, 1978; 1982; Daviron and Voituriez, 2003). Currently, these coordination modes are being denounced by a broad range of actors, reproaching them, amongst other things, of limiting the sovereignty and autonomy of States and companies, prohibiting them to define their own policies. One of the new facts of agricultural market regulation is the multiplication of standardization initiatives of private actors, especially from the retailing and processing sector, but also NGOs.

The World Trade Organization (WTO) has greatly expanded the scope of traditional trade and commodity agreements as set out in the GATT

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

GATT has defined rules on agriculture only with regard to setting trade quotas and tariffs (Ribier, 1996). Other matters have remained under the purview of national governments. Although not without flaws, this system has provided tools which allow countries to protect their domestic markets from the “dumping” of subsidized items and price ‘gouging’ by a handful of corporate commodity traders (reference?). 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 agriculture regulations have been particularly controversial because of strong feelings around the world that food should a basic human right and not a commodity subject to market competition and governed by the same trade rules that apply to products of industrial manufacturing (reference).

One of the side effects of the creation of WTO and the implementation of the trade agreements has been a worldwide increase in the number of food and food-borne disease.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	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 (reference?). In part this may simply be due to the increased volume of food imports, which has resulted in a reduction in the proportion of food products inspected (reference?). In the US the Food and Drug Administration inspections declined from 8% of total imports (excluding meat, poultry and processed eggs) in 1993 to only 1% in 2000 (reference?). The stricter adoption of food-safety inspection standards for foreign produce would violate the WTO’s and NAFTA’s rules requiring treatment by the exporting country, so guaranteeing that domestic and export goods be treated the same. Such a policy constrains a governments’ ability to set standards to protect its citizens.

The WTO’s Sanitary and Phytosanitary Agreement (SPS) has set criteria that member nations must follow regarding their domestic trade policies that affect food safety risks arising from additives, contaminants, toxins, veterinary drug and pesticide residues or other disease-causing organisms.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 to +4	G	Wide applicability

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 (reference?). The international standard is called the Codex Alimentarius (www.codexalimentarius.net). The problem that many member countries have with following the Codex standard is that the standards are often lower than national food and drug safety standards. For example, US standards on DDT residues are stricter than the Codex, so the U.S. violates its WTO treaty obligation if it does not allow in fruits and vegetables with DDT residue five times higher than the allowed domestic level (reference?). An indirect effect of this aspect of the SPS Agreement is that it encourages pesticide use and does not provide incentives for less-toxic agriculture technologies (reference?). Currently there is debate about the relevance of these standards to GM crops and animals (reference?). The SPS also sets parameters on member countries' domestic policies regarding livestock and fisheries).

3.2.4.3.3 Regional trade agreements: free-trade zones versus external protection and distortion

North American Free Trade Agreement (NAFTA) has had a major impact on food exports and agriculture systems.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	C	-3 to +2	R	North and South America

The implementation of NAFTA has had major social and economic impacts in agriculture and the trading of food, for example, resulting in the collapse of Mexico's corn production (reference). As part of the condition for joining NAFTA, Mexico had to change its Constitution and revoke the traditional 'ejido' system laws, a system of communal land and resource ownership, and also dismantle its system of maintaining a guaranteed floor price for corn, which sustained more than 3 million corn producers. The predictable result is that highly subsidized cheap corn imports surged into Mexico. Total US corn shipments to Mexico grew 17-fold between 1993 and 2001 and accounted for 25% of Mexican corn consumption compared to pre-NAFTA figure of 2% (reference?) Within a year Mexican corn production 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.

The sugar market is said to be the most heavily distorted agricultural market, buoyed up by US and EU support policies.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	C	-3 to 0	G	Wide applicability

Forty percent of the world's traded white sugar is exported by the EU (reference). This maintains a price support system, including intervention pricing, import duties, export refunds and quotas. This support system gives the EU a price 2-3 times greater than world prices (reference). Despite this, the policies do not succeed in supporting local farmers; instead they impose high costs on local consumers and higher costs on purchasers elsewhere, including developing countries (reference).

3.2.4.3.4. Structural adjustment policies

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
6	B	-3 to +1	G	Wide applicability

The structural adjustment policies were aimed at helping countries cut down their debt. Many SAPs required countries to cut spending (reference?) and 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 (reference?). 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 (reference?). Such financial mechanisms promoted monoculture crops requiring farm inputs such as commercial seeds, chemicals, fossil-fuel based machinery, as well as requiring an increase in water usage (Shiva, ???.)

Structural adjustment policies were supposed to promote export food commodities to foreign exchange earnings for poor countries so that they could then buy cheap imported food and pay off their debts.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
6	B	- 3 to 0	G	Wide applicability

Contrary to this expectation, the trend of wildly fluctuating commodity prices for export crops, many being at their lowest level in decades, has resulted in many developing countries spiraling even deeper into debt (reference?). An FAO study of how WTO policies affected farmers and food in 14 developing countries found that the cost of food imports rose in all the countries between 1995 and 1999 (FAO, ????) (WHOSE, page 197). Furthermore, a World Bank paper (Madeley, ???) concluded that trade liberalization has had a negative impact on the income growth of the poorest 40% of people in developing countries (Madeley, ???, pg. 89). Debts in developing countries are at an all-time high (reference ?)

One of the consequences of the structural adjustment policies has been that poor farmers have abandoned their land as they could no longer afford farm inputs.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3	B	-4 to 0	G	Mainly smallholder agriculture

Rising input prices have resulted in high migration from the countryside to already overcrowded urban centers in search of jobs, often low paying manufacturing jobs (reference?). In India, for example, numbers of landless rural farmers and peasants increased from 27.9 million to over 50 million between 1951 and the 1990s (Mittal, ????). This trend has been repeated in many countries. Other factors such as population growth, farm splitting at time of inheritance by children, etc. have also affected this migration.

3.2.4.3.5 The global AKST model that governed the past two decades

Evidence does not seem to support the theory that economic globalization is an import-export AKST food model that will boost income in developing countries and thus reduce poverty and hunger

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 6	C	-4 to 0	G	Wide applicability

While many factors affect the economy of a country, the following at least suggest that international policies have a long way to go to before the problems of poverty are resolved (Boussard, 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.
- In Brazil, despite growth in agricultural exports, hunger spread from one-third of the population in the 1960s to two-thirds by the early 1980s.
- 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 peasant 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.
- The USA lost over 38,000 small farms between 1995-2000, with net farm income 16% below average between 1990-1995.
- In Canada, farm debt 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.

The environmental cost of the transportation infrastructure required to support globalization has been overlooked.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	-3 to 0	G	Wide applicability

Increasing global food transport requires new infrastructure (airports, seaports, oilfields, pipelines, railways, highways, etc.). Many of these are built in wilderness, forested areas, coral reefs, etc. (reference). All of these transport systems increase the use of fossil fuel, with implications for climate change (reference). Ocean shipping carries nearly 80% of the world's international trade in goods and every tonne of freight moved by plane uses 49 times as much energy per kilometer as when it's moved by ship (reference?).

3.2.4.4 Emergence of new stakeholders

3.2.4.4.1 Stakeholders involved in the definition of policies, creating new norms and labels, and consolidating coordination mechanisms.

Increasing importance of standards: implication of consumer organizations and private firms

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 to +3	G	Wide applicability

New instruments of protection and competitiveness have emerged as 'standards' and new forms of coordination between actors of the food chain have been developed in response to consumer and citizen concerns. Actors work together in the food chain to specify the production conditions and impose them on their suppliers (reference). Initially limited to some companies, standards (e.g. Global Standard Food [GSF], International Food Standard [IFS], GFSI [Global Food Safety Initiative], FLO [Fair Trade Labelling Organisation]) are becoming global, associating firms of the whole world (reference). The multiplication of these standards, which are supposed to improve food safety, to preserve the environment, to reduce social disparities, etc., raises questions about their public regulation on a worldwide scale and the effective evaluation of their benefits (reference).

The globalization of the food supply chain has led to consumer concern for food safety and quality.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	-3 to 0	G	Wide applicability

The incidence of new food safety hazards such as the mad cow disease, contamination of fresh and processed foods (e.g. baby milk, hormones in veal, food colourings and ionized foodstuffs in Europe, mercury in fish in Asia, etc.) have resulted in the emergence of traceability as a key policy and scientific issue in food quality and safety. Over the past ten years considerable research efforts have 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). Concerns about growth-stimulating substances, GM food, dioxin-contaminated food and livestock epidemics (such as bovine spongiform encephalopathy), outbreaks of foot and mouth disease have given further impetus to organic food demand as consumers increasingly question the safety of conventional foods and industrial agriculture (reference). Several governments have responded to consumer concerns with declarations of targets for the expansion of organic production (reference). Many consumers perceive organic products as safer and of higher quality than conventional ones. These perceptions, rather than "science", drive the market (FAO, 2003 - http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3).

Public and media interest in food safety has increased.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 to +2	G	Wide applicability

Public interest in the chemical residues in fresh produce (Bracket, 1999; Kitinoja and Gorny, 1999) has followed 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 and their impacts on permitted thresholds of heavy metals (Alam et al., 2003;

Mansour, 2004), and their status as contaminants (FEHD 2002). The food administrators in developed countries have tended to set increasingly lower levels of tolerance, and traceability has become an important criterion of food quality (reference?).

Consumers' concerns about food safety have started to play a regulatory role in international trade.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	C	0 to +3	R	Wide applicability

The global trade affected by the implementation of food safety standards is valued at tens of US$ billion dollars (Otsuki et al., 2001; Jaffee and Henson, 2004; 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, which generates large value addition activities in developing countries (Hanak et al. 2002; World Bank 2005). This concept is supported by the changing structure of food trade and increasing market share of developing countries in fish, horticulture, livestock, oils and fats.

To ensure that the necessary safety characteristics for food are achieved, food standards have been developed.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 t0 +3	G	Wide applicability

Internationally recognized food safety standards include GAP, GMP like ISO 9000, EUREP GAP, HACCP, etc. (van Plaggenhoef et al., 2002). Similarly, various measures and standards have been developed for food quality, which include Diet Quality Index (Patterson et al., 1994), Analysis of Core Foods (Koehler, 1989; Kristal et al., 1990), and Healthy Eating Index (Kennedy et al., 1995). In addition, Dietary Diversity Scores are also now increasingly used to measure food quality (Hatloy, et al., 1998; Marshall et al., 2001; Kant et al., 1993 and 1995; Ali and Farooq, 2004). Ali and Tsou (2000) have developed a methodology to prioritize food commodities based on their total nutritive values. Although consumers benefit from the better quality and greater safety attributes of food products, the enforcement of food quality standards also raises some problems **(**Padilla, 1992). For example, it increases the costs of purchased food for the poor, and may generally affect the consumers adversely, through the loss of a competitive food market. Moreover, the enforcement of these food safety standards can be a drain on scarce public resources, and an additional burden for taxpayers, or may lead to rent seeking (reference).

The tightening of food standards appears to have benefited large-scale producers at the expense of smallholder producers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 6	C	-3 to +2	G	Wide applicability

The benefits accruing to large-scale producers are also have some spin-off benefits in terms of urban employment (reference), especially in product cleaning, handling, processing, and packing, etc. (reference?) The terms and conditions of this employment in the formal supply chains, although not optimal, are almost certainly better than in the informal sector, because many foreign buyers are imposing labor standards. Moreover, enforcement of food standards will improve their working environment, as workers in agriculture are typically exposed to unhealthy agricultural production practices and unsafe food (Ali and et al., 2005). To face the inequalities arising from benefits to large-scale producers, some standards have been developed to encourage small producers. The most prominent example is the development of the Fair Trade Movement (www.fairtrade.org.uk) from the late 1980s, which aims to ensure that poor farmers are adequately rewarded for the crops they produce (reference). This support has helped small organizations to market their produce directly. The scheme works in a similar market-led way to that of forest certification.

3.2.4.4.2 Increased partnerships between public and private actors, in response to new environmental issues

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

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	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 involvement of private sector investment, much of which has been multi-national, 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-fibre needs in addition to wood (Mayers and Vermeulen 2002),

Although many traditional forms of land husbandry and tenure do treat trees and food cropping as parts of one system, AKST development has rationalized production and separated agriculture from forestry.

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

New integrated agroforestry approaches reveal the advantages in maintaining close relationship between farming and forestry. Yet this desirable and unified approach is rarely visible in international institutions, national governments and markets (eg. World Commission on Forests and Sustainable Development (1999), and the Intergovernmental (now UN) Panel (now Forum) on Forests barely touched on agricultural links. Likewise the Inter Academy Council Report on African Agriculture (2004) paid scant attention to forestry, or even to agroforestry. The undesirable separation of these institutions means that typically they do not consider how to improve the evident synergies. Even the establishment of the World Agroforestry Centre within the CGIAR and the consequent worldwide growth of agroforestry, has seldom brought agriculture and forestry together institutionally. However, a few new forms of local organization and collective action, such as Landcare (Buck et al., ????,, Ecoagriculture (McNeely and Scherr, 2003), and community forestry associations (Molner, et al. 2005), are now emerging. For example, in Costa Rica rural development projects integrate forestry and farming in areas surrounding national natural reserves, creating biodiversity corridors like The Biological Corridor Alexander Skutch, a partnership between small landholder organizations and the Tropical Studies Center, close to Chirripó National Park. This project seeks to plant native forest and wood species within crop-producing lands, to create pathways for migrating birds, wild animals and protect the natural resources of the region (Canet, 2005).

There is increasing involvement of the private sector in agroforestry.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	C	0 to +2	G	Wide applicability

Typically, multinational companies have pursued large-scale, high input monocultures as their production systems. However, a small number of these firms are now recognizing the social, environmental, and even economic, benefits of community agroforestry. Interestingly, a few multi-national commercial companies are finding opportunities to engage in agroforestry as it develops new crop plants to meet specific needs in a diversifying economy where niche products can grow to become new international commodities (Mitschein and Miranda 1998; Unilever, Tchoundjeu et al., 2006; Wynberg et al., 2002), based on new public/private partnerships, such as those developed by the cocoa industry (Shapiro and Rosenquist, 2004). For example, starting 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 (Panik, 1998; Mitschein and Miranda 1998), while in Ghana, Unilever is developing new cash crops like Allanblackia sp. as shade trees for cocoa (IUCN, 2004). In South Africa, the ‘Amarula’ liqueur factory of Distell Corporation buys raw *Sclerocarya birrea* fruits from local communities (Wynberg et al., 2003). Public/private partnerships like these can set the standard for the integration of science, public policy and business best practices (Shapiro and Rosenquist, 2004).

In aquaculture, there is increased coordination of private sector-led production and processing chains.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	B	0 to +2	G	Wide applicability

Formal and informal links between smallholder producers and large processing companies are making aquaculture (eg. for shrimps, basa (Vietnamese catfish) and tilapia) become more efficient and competitive (reference), resulting to better quality assurance for consumers, secured margins for producers, and competitive prices for products (reference). Export certification schemes are further streamlining production, processing, distribution and retail chains (reference).

Access to water resources has been improved by water user associations and organizations, ensuring access to water rights through user-based allocations, agency allocations and market allocations.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5	B	0 to +3	G	Mainly in tropical countries

Water User Association (WUA) schemes in several states in India (Rajathan, Andhra Pradesh, Karnataka, West Bengal, Uttar Pradesh) have improved access to water resources and increased production through increased irrigation. Transferring irrigation management to farmers in Mexico, Turkey and Nepal has resulted in improved operation and management, a reduction in irrigation-related complaints about poor maintenance and deteriorating infrastructure, reduced government expenditures, and increased production (World Bank 1999**).**

3.2.4.4.3 New ways of organizing markets through institutional support

Seasonal fluctuation in fruit and vegetable supplies is one of the problems associated with the marketing of perishable products.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	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 market-based cold-storage, use of warehouse receipts in forwarding loans, and encouragement of future markets, and weather induced insurance, all of which can help to mitigate the impacts on the poor of seasonal fluctuations in cereals and perishables (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, that occur during the off-season (AVRDC, ????; Tchoundjeu et al., 2006).

Policy responses have been developed to enhance food and nutritional security, and food safety, and alleviate the impacts of seasonal fluctuations on the poor.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1	B	0 to +3	G	Wide applicability

Responses to food and nutritional insecurity have included: the provision of infrastructure for health facilities and mothers education (Alderman and Garcia 1994, Cebu Study Team 1992), programs ensuring equitable distribution of nutritious foods among family members (Carlona 1981; Kynch and Sen 1985), 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 (Stanton and Clemens 1987; Black et al 1982; Henry et al 1990). Other approaches to supporting marketing include: linking the domestic and international markets through involvement of the private sector, developing food aid, food-for-work program, policies to improve the predictability of forecasting models, and participatory approaches to agro-enterprise development (Ferris et al., 2006).

The food sector is processing a wider range of tropical products for tropical market diversification, locally and internationally.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 6	B	0 to +3	G	Wide applicability

Many different products can be processed from a single crop. For example, maize in Benin is processed into forty different products, and this in large part explains the limited penetration of imported rice and wheat into Benin. The branding of products with their area of origin is becoming an important marketing tool affecting the competitiveness of local products in the tropical food sector (reference). Likewise, competitiveness in the international market involves the promotion of the distinctive properties of tropical foodstuffs (e.g. colour, flavour, smell, texture; fat, carbohydrate, protein, mineral, vitamin content; thickening, setting or coagulative properties) in products such as tropical roots and tubers (cassava, yam, sweet potato, cana, aracacha, etc.), which have distinctive properties (e.g. resistance of starch to heat treatment, for use in frozen foods or baby foods) (reference). These developments promote local commodities on local markets and so minimize the negative impacts of globalization.

Many developing nations are developing policies to enhance incomes and reduce poverty by increasing the market participation by small-scale producers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
3, 6	B	0 to +3	G	Wide applicability

Improving the market participation of small-scale producersrequires better access to information, increased efficiency of input supply systems, provision of credit, and better market chains and infrastructure (Sautier, 2005). To ensure social sustainability it is important to know the impact of such activities on both poverty overall, its distribution in society and its impacts on the poorest. In some countries, agricultural policies and market liberalization have increased economic differentiation among communities and households (IFAD, 2003), and small-scale, low-input agriculture systems have an important role as a social safety net (Perret, 2003). Such nets help to maintain cultural and community integrity, promote biodiversity and landscape conservation. However, it is important to monitor and assess the impacts of these commercialization policies; with regard to the extent to which commercial production brings about changes in social values in the community, such as conflict, land ownership, kinship, and resource distribution (reference?).

3.2.4.4.4 The growing involvement of civil society and local organizations in the design of policies through AKST appropriation

Family farmer and rural organizations certainly represent, with the development of multinational firms, the major social, economic and political change in the last two decades regarding to agricultural and rural development.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
5	B	0 to +2	G	Wide applicability

In national and international arenas, civil society actors (NGO, family farmer organizations, etc) have been increasingly active in policy negotiations since the 1980s (Pesche, 2004). The emergence of new rural organizations and civil society intermediaries or support organisations coincides with trends of decentralisation (Mercoiret et al., 1997). This was followed in the 1990s, by the emergence and consolidation of federated regional civil society organizations (Touzard, 2003). For example, in West Africa, Roppa (Réseau des organisations paysannes et des producteurs d'Afrique de l'Ouest) was created in 2000 under the umbrella of UEMOA (Union Economique et Monétaire Ouest-Africaine). Similarly, in South America, Coprofam (Coordenadora de Organizaciones de Productores Familiares del Mercosul) was created at the time of the implementation of the Mercosur mechanisms, in order to defend family agriculture.

Family farmer organizations developed multiple functions that have had great impact as these organizations represent the interest of the very large majority of poor agricultural producers.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5, 6	C	0 to +3	G	Wide applicability

Farmer organizations enlarged their activities from production support to other functions, which are not all directed at economic profit-making (Bosc et al., 2002), such as coordination, political representation and defense of interests, elimination of illiteracy, training, improvement of cultivation methods for sustainability of production systems or social services. In some cases, these farmer organizations took direct responsibility for research and the dissemination of techniques (as in the Coffee Producer Federation of Colombia).

Cross-sectoral national forums associated with international agreements/summits, have developed strategic planning initiatives to provide an integrated framework for sustainable development

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4	C	0 to +3	G	Wide applicability

The action plans of the Rio Earth Summit (Agenda 21, 1992) and the World Summit on Sustainable Development (Johannesburg Plan, 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). Most countries have subsequently prepared national sustainable development and/or poverty reduction strategies. These have been most successful where they have: involved multi-stakeholder 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), been driven by high-level and 'neutral' government bodies, and been linked to expenditure reviews and budgets (Waldman 2005, Dalal-Clayton and Bass 2002). In Tanzania, for example, the poverty reduction strategy set cross-cutting environmental and social targets, and the Ministry of Finance asked for clarity on which sectoral and cross-sectoral bodies, including NGOs, could contribute to them; the government budget process was adapted to suit; this involved mechanisms for the involvement of non-government stakeholders (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. Moreover, because of a lack of updated information and data it is difficult to progress beyond a broad, consultative approach and identify specific trade-off decisions, especially concerning environmental issues (Bojo and Reddy, 20003).

3.2.4.5 Linking global and local AKST to address policy frameworks and prevent conflicts by taking into account land use and multi-functionality

3.2.4.5.1. From technocratic to participatory approaches to integrated Land Use Planning to address complex KST issues

The disciplines of land use planning and rural planning have been developed to bring together the different sectors of the rural economy, especially farming and forestry.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
5, 6	B	0 to +3	G	Wide applicability

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). These systems have played key roles in both the process of conversion of forest from a ‘land bank’ to farming, and in improving the productivity of farms and have been key tools of colonial powers, centrally-planned economies, and development agencies in the post-colonial era (Dalal-Clayton et al., 2003). At best, sectors are integrated at a watershed level or regional level, rather than at the on-farm level. The plans and the information systems associated with them, tended to reflect a highly technocratic, highly certain, top-down view of the way the world works – one that was not often recognized by stakeholders, especially politicians, and was neutral to all-important market influences (Dalal-Clayton et al., 2003). Consequently, technocratic land use planning has become less powerful.

Participatory land use planning has recently re-emerged highlighting its political and economic nature and its increasing concern with equity rather than merely productivity.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
5, 6	B	0 to +2	G	Wide applicability

Landuse planning is playing a new role in three major ways (Dalal-Clayton et al 2003). It has become: i) more decentralised, often being absorbed into district authorities – but usually with major capacity constraints which still result in blunt sector-based plans and which do not realize potential synergies, 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’. These approaches have led to better national conservation and development strategies (Vollet, 1997).

Integrating forestry with other land uses is having economic, environmental and social benefits.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	C	0 to +3	G	Wide applicability

Recently forest agencies have recognized that tree cover outside public forests and in farmland are as important for national forest-related objectives (FAO, 2006). As a result a number of initiatives are making substantial progress towards better environmental and social management. For example, 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* 2001a) and forest certification is beginning to be a mechanism to link 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 such as: biodiversity, carbon storage, tourism, agroforestry tree products, water and energy (Pagiola *et al* 2002; Belcher 2003; Scherr *et al* 2004). When KST and market conditions are right, the flow of financial benefits can make multi-purpose forest systems economically superior to conventional timber-focused systems (Pagiola *et al* 2002; Forest Trends 2005). Non-wood forest products produce a global value of at least $4.7 billion in 2005 (FAOI 2005)

3.2.4.5.2 Multifunctionality: a new concept to understand the complexity of agricultural and rural systems, referring to several KST

The production-oriented vision of agriculture was first questioned in the 1980's. Since then a 'multifunctional' concept of agriculture has been emerging.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2,3, 4, 5, 6	A	-5 to +5	G	Worldwide, but especially for the tropics

The multifunctional perception of agriculture in which farming produces environmental and social goods and services in addition to food has gradually been accepted (Barthélémy, 2003; Deffontaines, 1995). This change resulted from growing interest of consumers in traditional foods, ecotourism and the environment (Pecqueur, 2001) and also relied on farmers accepting new rewarding practices, such as diversification and direct marketing (Van den Ploeg, 2000). As the focus on multifunctionality increased, a new analysis emerged (OECD, 2001), which is now seen in this IAASTD report.

The concept of multifunctionality in agriculture and rural areas has opened the way to changes in policies, research and operational issues.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	-5 to +5	G	Worldwide

Multifunctional agriculture became a new policy goal in Europe in 2000 (European Agenda 2000), 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, 2004). However, it is not limited to developed countries and in some developing countries, notably Brazil, multifunctional agriculture has impacted on policies for family agriculture (Losch, 2004), and was advocated as a sustainable approach to landuse in Africa (Leakey, 2001 a/b). 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.

Rural development in developing countries is recognized as a multi-functional task in which agricultural and non-agricultural business come together in the rural territories.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	0 to +4	G	Wide applicability

Rural development is 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: (i) farmers integrated into the appropriate agricultural production-trade chain with dynamic links to social, economic and environmental activities in their region. In this way 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 (Arraya, ????)

3.2.4.5.3 Integrating systems at different levels: local, national, global

Conflicts and social disorders have considerable impact on agricultural production, although it has not received much research attention

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
5	D	-5 to 0	G	Wide applicability

Agricultural stagnation can in many cases be the cause of the development of illegal activities (Geffray, 1990) or conflicts (Lacoste, 2004). This is reinforced by factors like HIV and other diseases, urbanization, declining involvement of youth in agriculture and the decline of the agricultural workforce. Wars may arise from conflicts for agricultural resources (Collier, 2003), notably for land (Chauveau, 2003) or claims on forest (Richard, 1996). The impacts of wars and civil disorders exacerbate these problems, as they further reduce the availability of food (Macrae and Zwi, 1994; Stewart, 1993; Dreze and Sen, 1990). Although difficult to quantify, the agricultural losses related to wars have been increasing since the 1990's (FAO, 2000). Wars mostly cause indirect effects, such as a reduction of agricultural labor, destruction of storage and transformation infrastructures, ground and water pollution, obstacles to the movement of goods. Additionally, a decrease in the availability of agricultural inputs results in a loss of the agricultural productivity. Livestock husbandry is often particularly badly affected. Other impacts of war include the difficulty of marketing products, increased food prices, and reduced access of poor populations to food. Post conflict programmes may alleviate difficulties. This is particularly the case with the reorganisation 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).

Issues of land insecurity, inequitable distribution of land, social conflict, have been mitigated by an integrated approach to the examination of land management that take into account the plurality of systems, of local authorities and of land rights.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
5	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. In the Sahel, for example, rather than absolute and exclusive ownership of land, rights of use and access are seasonal. Farmers only have exclusive rights to their land in the wet season when they are growing crops; in the dry season nomadic herdsmen have traditional rights to graze their livestock. Overcoming this could greatly improve the sustainability of sedentary farming in the Sahel, but social tensions would result from the enclosure of farmers' fields. Thus before implementing living fences to protect farmers crops, regional-scale, land use planning is needed to ensure that nomadic herdmen would still have access to watering holes, pasture and dry season fodder, etc. (Leakey et al., 1999). Understanding local land management allows to assess the impact of policies and to question their relevancy (Platteau, 1996; Ensminger, 1997; DeSoto, 2005). This has proved that individual land rights are not appropriate (LeRoy, 1996). Local rights and institutions are now recognized by the international authorities (Deininger and Binswanger, 2001; World Bank, 2003) and entitlement policy is not considered any more as the single solution. Beyond the identification of the various regulation authorities (Schlager et Ostrom, 1992) the stake is now to articulate the local level with higher ones (national and international levels) (Lavigne Delville, 1998; Mathieu et al, 2000).

Territories emerge as a new scale, intermediary between local issues and national issues.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5, 6	B	-3 to +3	G	Worldwide applicability

Agronomists have recently adopted the concept of territory, derived from military and ecology vocabulary to develop integrated approaches to rural development (Sepulveda et al., 2003; Caron, 2005). Territory is seen as a portion of space, which delimitation is controlled by a social group that implements coordination institutions and rules. Applied to agricultural production, the concept helps in addressing disconnects between scales regarding ecological processes, individual decisions, collective management and policies. As it is controlled by local stakeholders, it also strengthens participation in designing new activities and policies to reduce or prevent marginalization, by promoting multi-functionality, as shown by the example of the French 'Territorial Management Contract' (*Contrat Territorial d'Exploitation*, CTE) implemented through the 1999 Agricultural Act. The objectives of this tool have been partially reached (Urbano and Vollet, 2005) in areas where, through contracts between government and farmers, the supply of high quality products has been increased while protecting natural resources, biodiversity and landscapes.

National conservation and development strategies now integrate development and sustainability goals from local to national level.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
4, 5, 6	B	0 to +3	G	Wide applicability

These strategies have often gained as much political profile as land use planning. National poverty reduction strategies, conservation strategies, and sustainable development strategies form a pool of approaches that attempt to re-wire institutions in a cross-cutting way, to engage local stakeholders in participatory processes to negotiate broad visions of the future, and to focus local, regional and national institutions on working together to achieve specific local and global outcomes, such as poverty reduction, environmental sustainability (Tubiana, 2000), and sustainable development (Dalal-Clayton and Bass 2002), as well as participatory agro-enterprise development (Ferris et al., 2006).

Concerns about growth-stimulating substances, GM food, dioxin-contaminated food and livestock epidemics (such as bovine spongiform encephalopathy), outbreaks of foot and mouth disease have given further impetus to organic food demand as consumers increasingly question the safety of conventional foods and industrial agriculture.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 2, 3, 4, 5	B	-3 to +3	G	Worldwide

Several governments have responded to consumer concerns with declarations of targets for the expansion of organic production. Many consumers perceive organic products as safer and of higher quality than conventional ones. These perceptions, rather than “science”, drive the market (FAO, 2003 - http://www.fao.org/DOCREP/005/Y4252E/y4252e13.htm#P11_3).

Over the last twenty years there have been a series of international trade initiatives aimed at boosting agricultural production, but these have typically been more beneficial to the economies of Developed Countries than to those of Developing Countries, despite the declared objective of promoting the failing economies of some of the world’s poorest countries.

GOALS	CERTAINTY	RANGE OF IMPACTS	SCALE	SPECIFICITY
1, 3, 4, 5, 6	B	0 to +3	G	Wide applicability

From the social perspective, the development of the Fair Trade movement from the late 1980s has aimed at ensuring that poor farmers are adequately rewarded for the crops they produce, and are helped to strengthen their own organizations and market their produce directly, works in a similar market-led way to forest certification (www.fairtrade.org.uk).

3.3 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 multi-functionality of agriculture.

The overriding lesson of this chapter is that the global focus of AKST to date on production issues has been at the expense of environmental and social sustainability. Consequently, natural resources have been overexploited and the social fabric of society has been eroded, such that the negative impacts are starting to outweigh the positives. The sustainable implementation of AKST has been impeded by inadequate understanding, inappropriate policy interventions, socio-economic 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 sustainable approaches to more socially-relevant, pro-poor, agriculture, and its 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 Integrated Natural Resources Management (INRM). It has a stronger emphasis on environmentally and socially sustainable agriculture and offers hope of a better future for all humanity. 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 first of the four questions posed by the IAASTD Secretariat: "*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 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 smallholder farmers.

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 smallholder 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 an overstorey 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 well-being 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 is 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 traditional diets of 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 smallholder 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. 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, socio-economic 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 and technical schools), and support the good work of many NGO's 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 socio-economic disciplines.

Ninth, AKST has suffered from poor linkages between 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 multi-functionality 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. 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 draw on some of the means available to globalized approaches that can improve connectedness, in order to scale up the more durable and sustainable aspects of the community-oriented ‘grassroots’ pathway on the one hand and 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, which serves to increase benefit flows to poor countries, and to marginalized people everywhere. This will involve scaling up 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, fulfilling the African Proverb:

“If many little people, in many little places, do many little things, they will change the face of the world”.

This will also require that developed country economies and multi-national 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 above ten lessons above have drawn very broadly on the literature. An informative and encouraging end to this Chapter is offered by a specific lesson-learning exercise covering 286 resource-conserving agricultural interventions in 57 poor countries (Pretty et al., 2006). It offers an illustration of the potential of implementing more sustainable approaches to agriculture with existing strategies and technologies. This study covered 3% of the cultivated land in developing countries (37M ha) and has shown increased productivity on 12.6 M 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 0.35t C $ha^{-1}y^{-1}$ thus if 25% of the area under these farming systems adopted sustainability enhancing technologies, global carbon sequestration could be 0.1 Gt y^{-1}. Pretty et al. (2006) concluded that with regard to meeting future food needs there are grounds for cautious optimism with poor farm households benefiting the most from the adoption of these resource-conserving interventions. Thus great strides forwards can be made by the wider adoption and up-scaling of existing pro-poor technologies for sustainable development. These can be greatly enhanced by further modification and promotion of some of the socially- and environmentally-appropriate AKST described in this chapter.

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