# IAASTD Global Report Chapter 2

# Historical Analysis of the Effectiveness of AKST Systems in Promoting Innovation

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## Key Messages

1. **Acknowledging and learning from competing and well evidenced historical narratives of knowledge, science and technology processes and understanding the flaws in past and existing institutional arrangements and maintaining the space for diverse voices and interpretations is crucial for designing policies that are effective in reaching the integrated goals of productivity, environmental sustainability, social equity and inclusion.** Agricultural Knowledge, Science and Technology (AKST) encompass diverse agricultural practices, interventions, institutional arrangements and knowledge processes. Different and often conflicting interpretations of the contributions of AKST to productivity, environmental and social sustainability and equity exist side-by-side but are not equally heard or recognized. Political power and economic influence have tended to privilege some types of AKST over others. Dominant institutional arrangements have established the privileged interpretations of the day and set the agenda for searching for and implementing solutions. The narrative used to explain past events and AKST choices has important implications for setting future priorities and projecting the future design of AKST.

2. **In the prevailing AKST arrangements of the past, key actors have been excluded or marginalized.** Preference has been given to short-term goals vs. longer-term agroecosystem sustainability and social equity and to powerful voices over the unorganized and voiceless. Development of appropriate forms of partnerships can help bring in the excluded and marginalized and open AKST to a larger set of policy goals. Many effective participatory approaches exist that facilitate the establishment and operation of such partnerships. Targeted public support can help address the biases in the dominant arrangements.

3. **The Transfer of Technology (ToT) model has been the most dominant model used in operational arrangements and in policy**. **However, the TOT model has not been the most effective in meeting a broader range of development goals that address the multiple functions and roles of farm enterprises and diverse agroecosystems.** In this model, science and technology are mobilized under the control of experts in the definition of problems and the design of solutions, problem setting and solving. Other types of knowledge have sometimes been tapped, although mainly for local adaptation purposes. Where the TOT model has been applied appropriately with the conditions necessary for achieving impact, it has been successful in driving yield and production gains. These conditions include properly functioning producer and service organizations, the social and biophysical suitability of technologies transferred in specific environments and proper management of those technologies at plot, farm and landscape levels.

4. **Successful education and extension programs have built on local and traditional knowledge and innovation systems, often through participatory and experiential learning processes and multi-organizational partnerships that integrate formal and informal AKST.** Basic and occupational education empowers individuals to innovate in farming and agroenterprises, adapt to new job opportunities and be better prepared for migration. Attention to overcoming race, ethnic and gender biases that hamper the participation of marginalized community members, diverse ethnic groups and women, is essential. Education and training of government policymakers and public agency personnel, particularly in decentralized participatory planning and decision-making, and in understanding and working effectively with rural communities and other diverse stakeholders has also proven effective. Effective options include but are not limited to experiential learning groups, farmer field schools, farmer research circles, Participatory Plant Breeding, social forestry and related community-based forest landscape management, study clubs and community interaction with school-based curriculum development.

5. **Investment in farmers and other rural actors' learning and capacity to critically assess, define and engage in locally-directed development processes has yielded positive results.** Modern ICTs are beginning to open up new and potentially powerful new opportunities for extending the reach and scope of educational and interactive learning. Extension and advisory services complement but do not substitute for rural education. The development and implementation of successful learning and innovation programs requires skills in facilitating processes of interaction among partners, interdisciplinary science and working with all partners' experience and knowledge processes. Active development of additional options are needed to extend these arrangements and practices to include more marginalized peoples and areas and in ways that respect and uphold their roles, rights and practices.

6. **Innovation is a multi-source process and always and necessarily involves a mix of stakeholders, organizations and types of knowledge systems.** Innovative combinations of technology and knowledge generated by past and present arrangements and actors have led to more sustainable practices. These include for example, integrated pest management, precision farming, local innovations in crop management (e.g., push-pull in Africa). Further experimentation with facilitated innovation is needed to capitalize on new opportunities for innovation under market-oriented development.

7. **Partnerships in agricultural and social science research and education offer potential to advance public interest science and increase its relevance to development goals**. Industry, NGOs, social movements and farmer organizations have contributed useful innovations in ecological and socially sustainable approaches to food and agriculture. Increased

private sector funding of universities and research institutes has helped fill the gap created by declining public sector funds but has mixed implications for these institutions' independence and future research directions. Effective codes of conduct can strengthen multistakeholder partnerships and preserve public institutions' capacity to perform public good research.

8. **Public policy and regulatory frameworks informed by scientific evidence and public participation and international agreements have enabled decisive and effective global transitions towards more sustainable practice**. New national, regional and international agreements will be needed to support further shifts towards ethical, equitable and sustainable food and agriculture systems in response to the urgent challenges posed by declining availability of clean water, climate change, and insupportable labor conditions.

9. **Awareness of the importance of ensuring full and meaningful participation of multiple stakeholders in international and public sector AKST policy formation has** increased. For example, in some countries, pesticide policies today are developed by diverse group of actors including civil society and private sector actors, informed by science and empirical evidence and inclusive of public interest concerns. These policies have focused on the multifunctionality of agriculture.

10. **The number and diversity of actors engaged in the management of agricultural resources such as germplasm has declined over time. This trend reduces options for responding to uncertainties of the future. It increases asymmetries in access to germplasm and increases the vulnerabilities of the poor.** Participatory plant breeding provides strong evidence that diverse actors can be engaged in an effective practice for achieving and sustaining broader goals of sustainability and development by bringing together the skills and techniques of advanced and conventional breeding and farmers' preferences and germplasm management capacities and skills, including seed production for sale. Further development and expansion would require adjustment of varietal release protocols and appropriate policy recognition under Union for the Protection of Plant Varieties (UPOV).

11. **The debates surrounding the use of synthetic pesticides have led to new arrangements that have increased awareness, availability and effectiveness of the range of options for pest management.** Institutional responses have included the strengthening of regulatory controls over synthetic chemical pesticides at global and national levels, growing consumer and retail markets for pesticide-free and organic products, removal of highly toxic products from sale, development of less acutely toxic products and more precise means of delivery and education of users in safe and sustainable practices. What constitutes safe and

sustainable practice has been defined in widely varying ways by different actors reflecting different conditions of use as well as different assessments of acceptable tradeoffs. The availability of and capacity to assess, compare and choose from a wide range of options in pest management is critical to strengthening farmers' ability to incorporate effective strategies that are safe, sustainable and effective in actual conditions of use.

12. **Integrated Pest Management exemplifies a flexible and wide-reaching arrangement of actors, institutions and practices that better address the needs of diverse farmers.** Although definitions, interpretations and outcomes of IPM programs vary widely among actors, IPM typically incorporates KST from a broad range of sciences, including social sciences, and the experience and knowledge of a diverse set of actors. IPM has become more common in high value production systems and has been adopted by an increasing number of important commercial actors in food processing and retailing. Successful approaches to introducing IPM to small-scale producers in the tropics include farmer field schools, push-pull approaches, advisory services provided under contractual arrangements for supply to central processing facilities and creative use of communication tools such as farmer-to-farmer videos and focused-message information campaigns. A combination of such approaches, backed by strong policy reform to restrict the sale of out-dated and highly toxic synthetic controls, will be needed to meet future development goals. Further experimentation with and operational fine-tuning of the institutional arrangements for IPM in the field in different settings is also needed to ensure optimal efficacy. These can be evaluated by comparative assessment using a combination of social, environmental and economic measures that include positive and negative externalities.

13. **Local food systems, known to sustain livelihoods at micro level, are currently challenged by globalized food systems.** This trend brings opportunities but also threatens livelihoods and sovereignties of marginalized communities and indigenous peoples. In some countries, social, ethical and cultural values have been successfully integrated in commercial mechanisms. Fair trade and ethnic labeling are examples of institutional options that can be considered by those who wish to promote effective measures to protect the interests of the marginalized and revitalize rural livelihoods and food cultures. The addition of a geographic indication can promote local knowledge and open opportunities for other agroenterprises such as tourism and specialty product development, as well as collaboration with utilities such as water companies. Production systems dominated by export markets are weakened by erratic changes in international markets and have sparked growing concerns about the sustainability of long-distance food shipping and the ecological footprint and social impacts of international trade practices. Local consumption and domestic outlets for farmers' products can alleviate the risks inherent in international trade.

## 2.1. Science, Knowledge, Technology and Innovation in Agriculture

The Asian AgriHistory Foundation translates historical writings that remind us that formal processes for generating technology-led innovation were in place in some countries more than 3000 years ago. This subchapter focuses on AKST processes and institutional arrangements, how these have been brought to bear on agricultural problems and combined to bring about innovation in agricultural systems when mobilized for different policy purposes. Subchapter 2.2 assesses the roles that various knowledge actors have played in different contexts, noting changes over time from different perspectives so as to minimize the risk that past actions are judged by current values or by those of only one set of actors. The drivers are assessed at three levels – local, regional, global. The assessments are further elaborated (2.3) in order to provide depth and detail in terms of three thematic narratives – (1) genetic resources management; (2) pest management; (3) food system management.

### *2.1.1 The specificity of agriculture as an activity*

At the beginning of the period under assessment, policy makers and other knowledge actors around the world had vividly in mind the fact that food is a basic necessity of life and that its supply and distribution is vulnerable to a range of disruptions that cannot always be well controlled. Only for those for whom food is reliably abundant can food be treated as an industrial good subject to the laws of elasticity of price. The special characteristics of farming as a human activity for supplying a basic necessity of life and as the cultural context of existence for a still large if declining proportion of the world’s people are central to meaningful historical assessment of AKST.

#### 2.1.1.1. The characteristics of agriculture as a multidimensional activity

Agriculture is based on local management decisions made in interaction with the biophysical, ecological and social context, this context to a large extent itself evolving independently of agriculture. It follows that AKST includes both a set of activities that happen to deal with the particular domain of agriculture and activities that necessarily co-evolve with numerous other changes in a society. AKST thus involves many types of knowledge and many suppliers of that knowledge acting in relation to vast numbers of (semi) autonomous enterprises and decision makers. This characteristic has provided special challenges but also opportunities in the design of institutional arrangements for AKST (Yunus and Islam, 1975; Yunus, 1977; Izuno, 1979; Symes and Jansen, 1994; Scoones et al., 1996; Buck et al., 1998; Stroosnijder and Rheenen, 2001; Edgerton, 2007).

*A place-based activity.* Agriculture as a place-based activity relies on unique combinations of bioclimatic conditions and local resources in their natural, socioeconomic and cultural dimensions. Agricultural practices depend on and also influence these conditions and resources (Herdt and Mellor, 1964). Specific knowledge of the locality is an asset decisive for the outcomes actually achieved through application of any technology (Loomis and Beagle, 1953; Hill, 1982; Giller, 2002; Tittonell et al., 2005, 2007; Vanlauwe et al. 2006; Wopereis et al., 2006; Zingore et al., 2007) yet a dominant trend over the period is the evolution of agricultures driven by nonlocal changes and by the introduction of technologies designed by actors and in places far removed from their site of application (Merton, 1957; Biggs, 1978; Anderson et al., 1991; Seur, 1992; Matson et al., 1997; Harilal et al., 2006; Leach and Scoones, 2006). This trend has been tightly associated with the adoption of a science-based approach to the industrialization of farming. It has allowed greater control by farmers of production factors and the simplification and homogenization of production situations particularly for internationally-traded commodities and high-value crops (Allaire, 1996).This has enabled large surpluses of a narrow range of basic grains and protein foods to be generated, traded and also moved relatively quickly to meet emergency and humanitarian needs. It has eased hunger and reduced poverty as well as kept food prices stable and low relative to other prices and allowed investment in other economic sectors (FAO, 2004). However, the ecological and cultural context of farming is always and necessarily 'situated' and cannot – unlike functions such as water use or carbon trading – be physically exchanged (Berkes and Folke, 1998; Hubert et al., 2000; Steffen et al., 2004; Lal et al., 2005; Pretty, 2005). Advances especially in the ecological sciences and socioeconomic research as well as drivers originating in civil society movements (2.2, 2.3) have mobilized science, knowledge and technology in support of approaches appreciative of place-specific, multidimensional and multifunctional opportunities (Agarwal et al., 1979; Byerlee, 1992; Symes and Jansen, 1994; Gilbert, 1995; de Boef, 2000; INRA, 2000; Fresco, 2002). Examples include (Cohn et al., 2006), trading arrangements connecting those willing to pay for specific ecological values and those who manage the resources that are valued (Knight, 2007), urban councils using rate levies to pay farmers for the maintenance of surrounding recreational green space or for ecosystem services such as spreading flood water on their fields; hydroelectric companies such as Brazil-Iguacú paying farmers to practice conservation tillage to avoid silting behind the dams and improve communal water supplies; farmers' markets; and community-supported agriculture.

*An embedded activity.* The resulting flows of products and services are embedded in a web of institutional arrangements and relationships at varying scales, such as farmers' organizations, industrial districts, commodity chains, *terroirs*, production areas, natural resource management areas, ethnic territories, administrative divisions, nations and global trading networks. Farmers are simultaneously members of a variety of institutions and relationships that frame their opportunities and constraints, offering incentives and penalties that are sometimes contradictory; farmers require strategic ability to select and interpret the relevant information constituted in these institutions and relationships (Chiffoleau and Dreyfus, 2004). The various ways of organizing science, knowledge and technology over the last sixty years have taken different approaches to farmers' strategic roles (2.1.2).

*A collective activity.* Farmers are not wholly independent entrepreneurs; their livelihoods critically depend on relationships that govern access to resources. With asymmetrical social relations, access is not equitably or evenly distributed. Individuals, groups and communities attempt to cope with inequalities by developing relational skills and capacity for collective action that help them to protect or enhance their access to and use of resources (Barbier and Lémery, 2000); the form that collective action takes changes over time and place and between genders. As commercial actors such as supermarkets have become dominant in food and farming systems, many farmers have transformed their production-oriented organizations into market-oriented organizations.

*A disadvantaged activity.* Agriculture is disadvantaged as an economic sector in the sense that the majority of small-scale producers and farm workers even today, in developing countries particularly, suffer from restricted access to formal education and opportunities to learn more about science and technology. Women and indigenous communities in particular tend to be more disadvantaged than others in this respect (Moock, 1976; Muntemba and Chimedza, 1995; ISNAR, 2002; IFAD, 2003; FAO, 2004; UNRISD, 2006). Investment in educating farmers in their principal occupation has been low compared to need throughout the period in most contexts. Master Farmer classes, Farmer Field Schools, study clubs, land care groups and interactive rural school curricula are among the options that have been developed in part simply to fill the gaps; few assessments exist of their comparative cost-effectiveness as educational investments. The potential of AKST to stimulate economic growth is affected in multiple ways by educational opportunity although these effects have not been well quantified (Coulombe et al., 2004; FAO, 2004). Overcoming educational disadvantages by contracting out extension to private suppliers as in Uganda poses new challenges (Ekwamu and Brown, 2005; Ellis and Freeman, 2006).

Wherever the structural and systemic disadvantages have been coupled to a lack of effective economic demand among cash-poor households, farmers in most parts of the developing world have been excluded also from formal decision making in agriculture and food policy and from priority setting in agricultural research unless special arrangements have been made to include them, such as the PRODUCE foundations in Mexico (Paredes and Moncado, 2000; Ekboir et al., 2006). Even under these arrangements it is the better educated and socially advantaged who participate; the inclusion of poor farmers, women, and laborers in research agenda-setting typically requires additional effort, for example by use of Citizen Juries (Pimbert and Wakeford, 2002). Given poor farmers' relative lack of education they also have been and remain vulnerable to exploitation in commercial relations (Newell and Wheeler, 2006), a growing problem as competitive markets penetrate deeper into rural areas. Market-oriented small-scale agriculture in developing countries is disadvantaged also by the huge and growing gap in the average productivity of labor between small-scale producers relying mainly on hand tools and the labor efficiency of farmers in areas that contribute the largest share of international market deliveries (Mazoyer, 2005; Mazoyer and Roudard, 2005).

#### 2.1.1.2 The controversy on multifunctionality

How AKST should or could address multifunctionality is controversial; while some have sought to balance the multiple functions of agriculture others have made tradeoffs among them, creating large variation in outcomes at different times and in changing contexts. The concept of multifunctionality itself has been challenged (Barnett, 2004). In general (Fig. 2-1) it refers to agriculture as a multi-output activity producing not only commodities (food, fodder, fibers, biofuel and recently pharmaceuticals) but also non-commodity outputs such as environmental benefits, landscape amenities and cultural heritages that are not traded in organized markets (Blandford and Boisvert, 2002). The frequently cited working definition proposed by OECD in turn associates multifunctionality with particular characteristics of the agricultural production process and its outputs: (i) the existence of multiple commodity and non-commodity outputs that are jointly produced by agriculture; and that (ii) some of the non-commodity outputs may exhibit the characteristics of externalities or public goods, such that markets for these goods function poorly or are nonexistent (OECD, 2001).

INSERT Fig. 2-1. Multiple outputs produced from farm inputs.

A multi-country FAO study, Roles of Agriculture, identified the multifunctional roles of agriculture at different scales (Table 2-1). The project’s country case studies underlined the many cross-sector links through which agricultural growth can support overall economic growth and highlighted the importance to sustainable farming of balancing the interests of rural and urban populations; social stability, integration, and identities; food safety and food cultures and the interests of nonhuman species and agroecological functioning.

INSERT Table 2-1. Roles of agriculture.

In the early years under review the multifunctionality of agriculture was under-valued in the tradeoffs made in technology choices and in formal AKS arrangements that were responding to urgent needs to increase edible grain output and high protein foods such as meat or fish. The success in meeting this essential but somewhat narrow goal tended to lock AKST into a particular pathway that perpetuated the initial post World War II focus. The political environment evolved in a direction that gave further stimulus to the organization of AKST devoted to the production of internationally traded goods (as advocated, for example, by the Cairns group of nations) rather than to sustaining multidimensional, place-based functionality in both its biophysical and sociocultural dimensions. This suited the circumstances of countries with large agricultural trade surpluses and relatively few small-scale producers in the areas where the surpluses were grown (Brouwer, 2004). For the majority of nations agriculture throughout the period has remained a domestic issue, based in part on large numbers of small-scale producers who still need to ensure basic food security and here a different calculus of interests (Conway, 1994). Countries such as Japan, Switzerland, Norway and the European Union opted for re-directing AKST toward maintaining the multifunctional capacity of agriculture once food surplus was assured (De Vries, 2000; Huylenbroeck and Durand, 2003; Sakamoto et al., 2007). In recent decades, changes in consumer demand and renewed emphasis by citizens on food quality, ethical issues, rural community livelihoods as well as changes in policy concerns (including resource conservation, , tourism, biomass energy production and environmental sustainability) have led to expectations in many countries that agriculture will be able to play a balanced and sustainable role in meeting multifunctional goals (Cahill, 2001; Hediger and Lehmann, 2003; Rickert, 2004; Paxson, 2007).

Debates about multifunctionality were taken up by the OECD and FAO leading to a clarification of the policy implications and a broader recognition among trading partners that agriculture does play multiple roles and that AKST arrangements can and do have a part. The additional broad benefits potentially associated with multifunctional agriculture, including conservation of biodiversity, animal welfare, cultural and historical heritage values and the liability and viability of rural communities (Northwest Area Foundation, 1994; de Haan and Long, 1997; Cahill, 2001; Hediger and Lehmann, 2003) were in many countries returned to core AKST agendas. A growing body of evidence concerning the social and environmental costs of past and current tradeoffs among functions also began to be systematically quantified (Pimentel et al., 1992, 1993; Pretty and Waibel, 2005; Pretty, 2005a; Stern, 2006) as well as the benefits of re-introducing multifunctionality to industrial agricultural environments (NRC, 1989; Northwest Area Foundation, 1995; Winter, 1996; Buck et al., 1998).The role of local knowledge and technology processes also became more widely recognized and formed the basis of AKST arrangements that sought to offer rural youth a motivation and realistic opportunities to stay in farming and develop agroenterprises (Breusers, 1998; FAO, 2004; Richards, 2005).

At some scales the multifunctional roles and functions that different agricultural systems actually play today are well described for many contexts and are non-controversial. However, many of the variables are difficult to assess and are recognized as requiring the development of new knowledge routines if they are to be addressed adequately (Raedeke and Rikoon, 1997). In particular, some of the ecological and social goods, services and amenities that are not subject to commercial transactions have proven difficult to measure and hence in recent years greater reliance has been placed on developing alternatives. These include the use of relevant and efficient proxy indicators (Akca, Sayili, and Kurunc, 2005; Mukherjee and Kathuria, 2006), 'water footprint' estimations (Hoekstra and Chapagain, 2007; Chapagain and Hoekstra, 2003) that show the extent to which farming systems, production practices, consumption patterns and the composition of agricultural trade affect net water balances at national levels (Chapagain and Hoekstra, 2003) and environmentally adjusted macroeconomic indicators for national economies (O'Connor, 2006). The experience has been mixed of applying these to actual decision-making. Developing and using computer-simulated modeling of multifunctionality (McCown et al., 2002) at field-scale (e.g. McCown et al., 1996) or farm-to-landscape scale (e.g. Parker et al., 2002) has led to robust applications in support of interactive learning among diverse users (Walker, 2002; van Ittersum et al., 2004; Nidumolu et al., 2007) seeking to balance interests in processes of adaptive management (Buck et al., 2001).

### *2.1.2. Knowledge processes*

*Knowledge processes* refer to the collective processes of creating, transforming, storing and communicating about knowledge (Beal et al., 1986). The organization of knowledge processes in agricultural development has been subsumed in powerful mental models of how science, knowledge and technology 'get agriculture moving' (Mosher, 1966; Borlaug and Dowswell, 1995). Each of the main models (Albrecht et al., 1989, 1990) has its own logic and fitness for purpose. They and their variants are discussed and compared; in each case for the sake of clarity they are first presented as commonly accepted abstractions followed by assessment of the dynamic ways in which the model has been applied within specific institutional arrangements in particular contexts. Institutional arrangements are important to the assessment because they provide different ways of distributing power and influence among sources of knowledge and hence are consequential for understanding the kinds of impact that can be expected and were in fact realized.

#### 2.1.2.1 Transfer of Technology as a model for organizing knowledge and diffusion processes

One model in particular has dominated as a guide to the organization of knowledge processes in the public sector in developing countries, the Transfer of Technology (ToT) model. It was formally elaborated as a practical model for guiding action and investment in specific AKST arrangements on the basis of empirical studies of knowledge management and diffusion processes in the mid-west of America (Lionberger, 1960; Havelock, 1969). Science is positioned in this model as a privileged problem-defining and knowledge generating activity carried out mainly by universities and research stations whose knowledge, embedded in technologies, messages, and practices is transferred by extension agents to farmers. The model assumes a linear flow of technological products and information. Each of the entities described in the model is treated more or less as a ‘black box’. Although in practice much local level interaction takes place between extension agents, farmers and research specialists, the underlying assumption of the model is that farmers are relatively passive cognitive agents whose own knowledge is to be replaced and improved as a result of receiving messages and technologies designed by others and communicated to them by experts (Röling, 1988; Compton, 1989; Eastman and Grieshop, 1989; Lionberger and Gwin, 1991; Blackburn, 1994; Röling and Wagemakers, 1998).

The model mirrored the prevailing AKST organizational arrangements of states gaining their independence in the 1950s and 60s. Many explicitly favored centrally-planned economic development and most relied heavily on state organizations as the catalyst of agricultural development and commodity marketing (Hunter, 1969, 1970; Dayal et al., 1976). Extension field staff were positioned on the lowest rung in a hierarchy of relationships under the direction of departments of agriculture and publicly funded research stations and universities (Maunder, 1972; Peterson et al., 1989). Social, educational and political biases reinforced the idea that lack of access to ‘modern knowledge’ was a constraint to production (Mook, 1974; Morss, et al., 1976). District development plans and projects to develop cooperatives, farmer service societies and the like received considerable attention (Halse, 1966; Lele, 1975; Hunter et al., 1976).

The ToT model assumes that wide impact is achieved on the basis of autonomous diffusion processes; this indeed can be so (Rogers, 1962). The classic study of *diffusion of innovations* was published in 1943 based on the rapid autonomous spread of hybrid maize among farmers in Iowa (Ryan and Gross, 1943). The diffusion of innovations became a popular subject for empirical social science research, generating well over 2000 studies and much was learned that was helpful concerning the conditions in which rapid and widespread diffusion can occur, what helps and hinders such processes and the limitations of diffusion for achieving impact. Diffusion research has continued even after the late Everett Rogers (well-known for his classic decadal overviews of research on the diffusion of innovations) (Rogers, 1962, 1983, 1995, 2003) himself spoke of the ‘passing of a dominant paradigm’ (Rogers, 1976). The role of autonomous diffusion among farmers persists as one of the pillars of the common understanding of the pathways of science impact. The history of the rapid spread in Africa of exotic crops such as cassava, maize, beans and cocoa is added testimony to the power of diffusion processes to change the face of agriculture even without the kinds of scientific involvement of more recent years.

*The positive impact of the ToT model*. The ToT model gained credibility from the rapid and widespread adoption of the first products of the Green Revolution (GR) emerging from basic and strategic research (Jones and Rolls, 1982; Evenson, 1986; Jones, 1986; Evenson and Gollin, 2003). For example, in the poor, populous, irrigated areas of Asia the GR allowed Bangladesh to move in 25 years from a net importer of rice to self sufficiency while its population grew from 53 million to 115 million (Gill, 1995) and India, Indonesia, Vietnam, and Pakistan to avert major famine and keep pace with population growth (Repetto, 1994). In China, wheat imports dropped from 7.2 tonnes in 1994 to 1.9 tonnes in 1997 and by 1997 net rice exports had risen to 1.1 tonnes. The Green Revolution not only increased the supply of locally available staples but also the demand for farm labor, increasing wage rates and thus the work-based income of the 'dollar-poor' (Lipton, 2005). National food security in food staples in the high population areas of developing countries throughout the world was achieved except in sub-Saharan Africa. The diet of many households changed as more milk, fish and meat became available (Fan et al., 1998). Investment in industrialized food processing and in agricultural engineering, often stimulated by heavy government subsidies, in turn began to transform subsistence farming into a business enterprise and created new employment opportunities in postharvest operations i.e., storage, milling, marketing and transportation (Sharma and Poleman, 1993). The ToT model clearly proved fit for the overall purposes of disseminating improved seed, training farmers in simple practices and input use and disseminating simple messages within the intensive, high external input production systems characterizing the relatively homogeneous irrigated wheat and rice environments of South and Southeast Asia. Positive impacts were recorded also in parts of sub-Saharan Africa (Moris, 1981, 1989; Carr, 1989).

*The ToT model's drawbacks with respect to development and sustainability goals.* Criticism of the ToT model began to emerge strongly in the late 1970s as evidence of negative socioeconomic and environmental impacts of the GR accumulated (UNRISD, 1975; Freebairn, 1995) leading to sharp controversies that are still alive today (Collinson, 2000). Sometimes a technology itself was implicated; in other cases the institutional and economic conditions for using a new technology effectively and safely were not in place or the services needed for small-scale producers to gain access to or realize the benefits were inadequate, especially for the resource-poor, the indigent and the marginalized and women (Hunter, 1970; Roling et al., 1976; Ladejinsky, 1977; Swanson, 1984; Jiggins, 1986). The loss of entitlements to subsistence brought about by changes in the agricultural sector itself and in societies as a whole; weather-related disasters; civil unrest; and war also left many millions still vulnerable to malnutrition, hunger, and starvation (Sen, 1981; Johnson, 1996). The evidence highlighted three areas of concern:

*Empirical*: The ToT model was shown to be unfit for organizing knowledge processes capable of impacting heterogeneous environments and farming populations (Hill, 1982) and did not serve the interests of resource-poor farmers in risky, diverse, drought prone environments (Chambers, 1983). In the absence of measures to address women's technology needs and social condition, technologies transferred through male-dominated extension services largely by-passed women farmers and women in farm and laboring households (Hangar and Moris, 1973; Leonard, 1977; Harriss, 1978; Buvinic and Youssef, 1978; Fortmann, 1979; Bettles, 1980; Dauber and Cain, 1981; Evans, 1981; Deere and de Leal, 1982; Safilios-Rothschild, 1982; Mungate, 1983; Carloni, 1983; IRRI, 1985; Gallin and Spring, 1985; Muzale with Leonard, 1985; Nash and Safa, 1985; Staudt, 1985; Gallin et al., 1989; Gallin and Ferguson, 1991; Samanta, 1995). In addition, the improved seeds rapidly displaced much of the genetic diversity in farmers' fields that sustained local (food) cultures (Howard, 2005) and which had allowed farmers to manage place-dependent risks (Richards, 1985); the higher use of pest control chemicals in irrigated rice in the tropics had detrimental effects on beneficial insects, soils and water (Kenmore et al., 1984; Georghiou, 1986; Gallagher, 1988; Litsinger, 1989) as well as on human health (Whorton et al., 1977; Barsky, 1984).The evidence of negative effects on equity was claimed by some to be a first generation effect. Analysis of data from the Northern Arcot region of Tamil Nadu, India, indicated that the differences in yield found between large and small-scale producers in the 1970s had disappeared by the 1980s (Hazell and Ramaswamy, 1991) but further empirical studies failed to resolve the extent to which the second generation effects were the result of 'catch up' by later adopters or the result of smaller farmers having lost their land or migrated out of farming (Niazi, 2004).

*Theoretical*: A basic assumption of the ToT model that 'knowledge' can be transferred was shown to be wrong. It is information and communications about others' knowledge and the products of knowledge that can be shared (Beal et al., 1986). No one is merely a passive 'receiver' of information and technology since every one engages in the full range of knowledge processes as a condition of human survival (Seligman and Hagar, 1972; Maturana and Varela, 1992; Varela et al., 1993). Information about people's existing knowledge, attitudes and practices was found to be a poor predictor of their response to new ideas, messages, or technologies because knowledge processes and behaviors interact with the dynamic of people's immediate environment (Fishbein and Ajzen, 1975). The organization of processes for generating knowledge that is effective in action (Cook and Brown, 1999; Hatchuel, 2000; Snowden, 2005) was shown to take many forms. Where the rights of individuals and communities to be agents in their own development and considerations of equity, human health, and environmental sustainability were important policy goals, the comparative advantages of the ToT model also appeared less compelling (Jones and Rolls, 1982; de Janvry and Dethier, 1985; Swanson, 1984; Jones, 1986).

*Practical:* The mix of organizational support and services needed to gain maximum impact from the ToT model often were inadequate, imposed high transaction costs or were not accessible to the poor and to women (Howell, 1982; Korten and Alfonso, 1983; Ahmed and Ruttan, 1988; Jiggins, 1989). The positive role of local organizations as intermediaries in rural development was demonstrated but also the tendency for agricultural services organized along ToT lines to by-pass these (Esman and Uphoff, 1984). The credit markets introduced to support technology adoption for instance typically were selective and biased in favor of resource rich regions and individuals (Howell, 1980; Freebairn, 1995) although pioneering initiatives such as the Grameen Bank in Bangladesh demonstrated that alternative approaches to the provision of microcredit to poor producers, women and farm laborers were possible (Yunus, 1982). Institutional analyses demonstrated how and why ToT arrangements that worked well in one context might fail to perform as well when introduced into other contexts. A recent authoritative assessment concludes that after 'twenty-five years in which agricultural extension received the highest level of attention it ever attracted on the rural development agenda' political support for ToT in the form of 'relatively uniform packages of investments and extension practices in large state and national programs' had disappeared (Anderson et al., 2006).

#### 2.1.2.2 Other models of knowledge generation and diffusion processes

By the early 1970s, empirical studies and better theoretical understanding indicated that better mental models of knowledge processes were needed to guide practice if broader development goals were to be reached (Hunter, 1970). The first wave of institutional innovation in the organization of knowledge processes in non-Communist states sought to make more effective the process of moving science 'down the pipeline' and technologies 'off the shelf' by creating mechanisms and incentives for obtaining feedback from producers so that their local knowledge and priorities could be taken into account in targeting the specific needs of different categories of farmers. The *Training and Visit (T&V) approach* is a particularly well known example of this effort (Benor et al., 1984). Heavily supported by the World Bank and became standard practice in the majority of noncommunist developing countries. Among other aims it sought to strengthen the management of diffusion processes by selection of 'contact' or 'leading farmers' and in some cases also contact groups. Extension agents report back 'up the line' the problems and priorities of the farmer and farmer groups that they trained during their fortnightly field visits (Benor et al., 1984). The T&V approach was criticized almost from its inception as an inadequate response to the widespread evidence of the limitations of ToT approaches (Rivera and Schram, 1987; Howell, 1988; Gentil, 1989; Roberts, 1989). Little remains today of national T&V investments and service structures (Anderson et al., 2006).

*Farming systems research and extension (FSRE)* is another well-known response. In this model feedback came directly through diagnostic surveys carried out by multidisciplinary teams, by farm level interactions between researchers and farmers in the course of technology design, testing and adaptation and by the organization of farmer visits to research stations (Rhoades and Booth, 1982; Bawden, 1995; Collinson, 2000). Wide impact in this case was sought by the designation of farming systems within agroecological 'recommendation domains' for which a specific technology or practice was designed to be effective and profitable. FSRE practitioners explicitly took into account the contextual conditions that might compromise the effectiveness or profitability of a problem-solution as well as sociocultural factors such as women's roles in farming. How well they managed to do so was disputed (Russell et al., 1989). FSRE produced interesting results but failed to have wide impact. Although largely abandoned as an institutional arrangement its influence lived on (Dent and McGregor, 1994) through methodological innovations addressing the highly differentiated livelihood needs of the rural poor (Dixon and Gibbon, 2001), the stimulus it gave to re-valuation of the multifunctionality of farming (Pearson and Ison, 1997) and the ways in which it forged connections across scientific disciplines that endure within the organizational arrangements of numerous research communities (Engel, 1990).

Neither T&V nor FSR-E addressed the institutional challenge of creating 'the mix' of support services necessary for articulating innovation along the chain from producer to consumer (Lionberger, 1986). In the private commercial sector the production of tea, coffee, palm oil, rubber, pineapples and similar commodities in the small-scale sector typically used the *core-estate-with-out-growers model* to address the challenge (Chambers, 1974; Hunter et al., 1976; Compton, 1989), positioning producers under contract to supply outputs to a processing facility that provided inputs and services. The company assumed responsibility for assembling the scientific and market knowledge required as well as the technology and infrastructure for securing company profits, drawing largely on knowledge resources in the home country or from within the company's international operations. The approach provided reliable income to producers, employees and companies and through commodity taxes or export levies to governments. It was criticized for locking small-scale producers into low income contracts. It also proved open to corruption when applied through government owned Commodity Boards, with profits siphoned off to intermediaries and elites (Chambers and Howe, 1979; Sinzogan et al., 2007).

The challenge was addressed in Communist states by state seizure of the means of production and by state control of the provision of inputs and services and the distribution of the product. The scientific knowledge base to support such a high degree of planning was strong. However, the means chosen within the prevailing ideology to translate knowledge generated at the scientific level into knowledge that was effective for practice was based on *command and control*. Support to the knowledge processes and experiential capacity of those actually working the land – albeit under direction of others – was not encouraged. In the exceptional historical experiences of states such as Cuba (Carney, 1993; Wright, 2005) or Vietnam state-directed knowledge processes contributed to basic food security but in general the command and control approach did not prove efficient in generating surplus nor a continuing stream of innovation in agriculture and became a source of vulnerability for state survival (Gao and Li, 2006). Since the fall of the Berlin Wall in 1989, the command and control model has been largely abandoned.

A parallel wave of innovation in the organizational design of knowledge processes was centered in producers' own capacity to engage in 'knowledge work' and on the role of local organizations in meeting development and sustainability goals (Chambers and Howes, 1979; Chambers, 1981). Models for what became known as Farmer Participatory Research and Extension (FPRE) were elaborated in practice by drawing on local traditions of association, knowledge generation and communication. Experience generated under labels such as Participatory Learning and Action Research, Farmer Research Circles, Community Forestry, Participatory Technology Development and FAO's People's Participation Program (Haverkort et al., 1991; Scoones and Thompson, 1994; Ashby, 2003; Coutts et al., 2005; IIRR, 2005) showed that if time is taken to create effective and honest partnerships in FPRE the results are significant and can offer new opportunities to socially marginalized communities and those excluded under other knowledge arrangements. They share a number of generic features *viz.* learner-centered, place dependent, ecologically informed and use of interactive communication and of facilitation rather than extension skills (Chambers and Ghildyal, 1985; Ashby, 1986; Farrington and Martin, 1987; Gamser, 1988; Biggs, 1989; Haverkort et al., 1991; Ashby, 2003). Science and off-the-shelf technologies are positioned as stores of knowledge and as specialized problem-solving capacities that can be called upon as needed. An FPRE approach has been used for example in the development and promotion of on-farm multipurpose tree species in Kenya (Buck, 1990) that had wide-scale impact and complemented the mobilization of women in tree-planting under the Green Belt movement (Budd et al., 1990).The development and promotion through farmer-to-farmer communication and training of a range of soil fertility and erosion control techniques in Central America similarly was based on an FPRE approach (Bunch and Lopez, 1994; Hocdé et al., 2000; Hocdé et al., 2002) as were integrated rice-duck farming in Bangladesh (Khan et al., 2005) and the testing and adaptation of agricultural engineering prototypes by farmer members of the Kondomin Group network in Australia. Nongovernment organizations (NGOs), community-based organizations (CBOs), universities and the Consultative Group on International Agriculture Research (CGIAR) played key roles in elaborating effective practice and supporting local FPRE initiatives (Lumbreras, 1992; Dolberg and Petersen, 1997; IIRR, 1996, 2005).

*Participatory Plant Breeding* (PPB) is a particular adaptation of FPRE: its client-oriented interactive approach to demand-driven research has been shown to be particularly effective for grains, beans and roots (de Boef et al., 1993; Sperling et al., 1993; Farrington and Witcombe, 1998; CIAT, 2001; Fukuda and Saad, 2001; Chiwona-Karltun, 2001; Mkumbira, 2002; Ceccarelli et al., 2002; Witcombe et al., 2003; Virk et al., 2005). It is a flexible strategy for generating populations, pure lines and mixes of pure lines in self-pollinated crops as well as hybrids, populations, and synthetics in cross-pollinated crops. Biodiversity is maintained or enhanced because different varieties are selected at different locations (Joshi et al., 2001; Ceccarelli et al., 2001ab). Recent assessments of over 250 participatory plant breeding projects in over 50 countries in Latin America, Europe, south and southeast Asia and sub-Saharan Africa led by farmers, NGOs or by national or international researchers or some mix of these actors (Atlin, Cooper, and Bjornstad, 2001; Joshi et al., 2001; Cleveland and Soleri, 2002; Ashby and Lilja, 2004; Almekinders and Hardon, 2006; Mangione, 2006; Ceccarelli and Grando, 2007; Joshi et al., 2007) demonstrate that PPB is a cost-effective practice that is best viewed along a continuum of plant breeding effort. French researchers, e.g., are working with marker-assisted selection to develop virus resistant rice varieties for Central America and the Cameroon in the context of PPB activities (www.ird.fr/actualites/2006/fas247.pdf). GIS and satellite-based imaging are adding additional value to PPB activities.

While over 8000 improved varieties of food grains with wide adaptability have been released over a 40-yr period by the CGIAR institutes (Evenson and Gollin, 2003), PPB has shown capacity to generate multiples of this output for target environments, specific problems and the needs of farmers over-looked by conventional breeding efforts. The three major differences of PPB compared to conventional breeding are that testing and selection take place on the farm instead of on-station; the key decisions are taken jointly by farmers and breeders; the process can be independently implemented in a large number of locations. The activity incorporates also seed production with farmers multiplying promising breeding material in village-based seed production systems. The assessments highlights also the improved research efficiencies and program effectiveness gained by faster progress toward seed release and the focus on the multiplication of varieties known to be farmer-acceptable. Decentralized selection in target environments for specific adaptations allows women's seed preferences to be addressed (Sperling et al., 1993; Ashby and Lilja, 2004; Almekinders and Hardon, 2006). Sustained PPB activity has the additional advantage of bringing about the progressive empowerment of individual farmers and farmer communities (Almekinders and Hardon, 2006; Cecccarelli and Grando, 2007). However, the tightening of UPOV regulations and the increasing trend toward seed patenting and IPR over genetic material has given rise to concern (Walker, 2007) that despite PPB's demonstrated advantages in a wide variety of contexts and for multiple purposes the space for PPB may be closing.

As the case of PPB shows, wider scale impact in the case of FPRE relies on the replication of numerous initiatives in response to specific markets and non-market demands rather than on supply-push and diffusion of messages or technologies, although diffusion processes can and do amplify the outcomes of FPRE. The process of replication can be strengthened through investment in farmer-to-farmer networking (Van Mele and Salahuddin, 2005), support to farmer driven chain development (as in poultry or dairy chains serving local markets) and in the creation of ‘learning alliances’ among support organizations that aim to promote shared learning at societal scales (Pretty, 1994; Lightfoot et al., 2002). FPRE has proved to be cost-effective and fit for the purposes of meeting integrated development and sustainability goals (Bunch, 1982; Hyman, 1992) and for natural resource management (NRM) in agrarian landscapes (Campbell, 1992, 1994; Hilhorst and Muchena, 2000; CGIAR, 2000; Stroosnijder and van Rheenen, 2001; Borrini-Feyerabend et al., 2004). However, it has been criticized for failing in specific cases to take advantage of the ‘best’ science and technology available, as self-indulgent by supporting farm systems that some consider insufficiently productive to provide surplus to feed the world’s growing urban populations; as sometimes misreading the gender power dynamics of local communities (Guijt and Shah, 1998) and as incapable of involving a sufficient number of small-scale producers (Biggs, 1995; Richards, 1995; Cooke and Kothari, 2001). NGOs and community-based organizations have raised issues of equity. It also been criticized as too locally focused (see critiques of Australia’s Landcare experience in Lockie and Vanclay, 1997; Woodhill, 1999) and thus unable to address higher level economic and governance constraints and tradeoffs. This criticism has prompted recent institutional experimentation with applying FPRE under catchment scale regional development authorities (Australia) and in sustainable water development (South Africa and Europe) (Blackmore et al., 2007) within normative policy frameworks that explicitly seek the sustainability of both human activity and agroecologies.

Innovations in the organization of knowledge processes also occurred in relation to farmer-developed traditions of agroecological farming (e.g. Fukuoka, 1978; Dupré, 1991; Gonzales, 1999; Furuno, 2001), gathering and domestication of wild foods and non-timber forest products (Scoones et al., 1992; Martin, 1995) and landscape management (Fairhead and Leach, 1996) . For example migrants from the Susu community first encountered the rice-growing ethnic Balantes in Guinea Bissau around 1920; later on, the Susu (and the related Baga peoples) hired migrant Balantes to carry out rice cultivation in the brackish waters of coastal Guinea Conakry where the skills are now recognized as traditional knowledge (Sow, 1992; Penot, 1994).

Indigenous technologies of long-standing include the use of Golden Weaver ants as a biocontrol in citrus and mango orchards (Bhutan, Vietnam and more recently, with WARDA's assistance, introduced to West Africa); stone lines and planting pits for water harvesting and conservation of soil moisture (West African savannah belt); *qanats* and similar underground water storage and irrigation techniques (Iran, Afghanistan and other arid areas); tank irrigation (India, Sri Lanka); and many aspects of agroforestry, e.g., rubber, cinnamon, and damar agroforests in Indonesia. Over the years they have supported wildlife and biodiversity and rich cultural developments.

It is this continuing *indigenous capacity for place-based innovation* that has been almost entirely responsible for the initial bringing together of the science, knowledge and technology arrangements for what have become over time certified systems of agroecological farming such as organic farming, confusingly known also as biological or ecoagriculture; (Badgely et al., 2007) and variants such as permaculture (Mollison, 1988; Holmgren, 2002). Systems such as these are knowledge-intensive, tend to use less or no externally supplied synthetic inputs and seek to generate healthy soils and crops through sustainable management of agroecological cycles within the farm or by exchange among neighboring farms. Although there is considerable variation in the extent to which the actors in diverse settings initially drew on formal science and knowledge, as the products have moved onto local, national, and international markets under various certification schemes the relationships between formal AKST actors and producer organizations have become stronger along the entire chain from seed production to marketing (Badgely et al., 2007). A distinctive feature in these arrangements is the role of specialist farmers in producing certified seed on behalf of or as members of producer organizations.

The relative lack of firm evidence of the sustainability and productivity of these kinds of certified systems in different settings and the variability of findings from different contexts allows proponents and critics to hold entrenched positions about their present and potential value (Bindraban and Rabbinge, 2005; Tripp, 2005; Tripp, 2006a). However, recent comprehensive assessments conclude that although these systems have limitations, better use of local resources in small scale agriculture can improve productivity and generate worthwhile innovations (Tripp, 2006b) and agroecological/organic farming can achieve high production efficiencies on a per area basis and high energy use efficiencies and that on both these criteria they may outperform conventional industrial farming (Pimentel et al., 2005; Sligh and Christman, 2006; Badgely et al., 2007). Despite having lower labor efficiencies than (highly mechanized) industrial farming and experiencing variable economic efficiency, latest calculations indicate a capability of producing enough food on a per capita basis to provide between 2,640 to 4,380 kilocalories/per person/per day (depending on the model used) to the current world population (Badgely et al, 2007). Their higher labor demand compared to conventional farming can be considered an advantage where few alternative employment opportunities exist. Organic agriculture as a certified system by 2006 was in commercial practice on 31 million ha in 120 countries and generating US $40 billion per year.

Innovations with comparable goals but originating in private commercial experience (Unilever, 2005) or in the context of partnerships among a range of farmers' organizations, public and private commercial enterprises by the mid 1990s were reported with increasing frequency (Grimble and Wellard, 1996). The Northwest Area Foundation experience in the USA (Northwest Area Foundation, 1995), the New Zealand dairy industry (Paine et al., 2000) or farming and wildlife advisory groups in the UK are among the numerous compelling examples of an emerging practice. They indicate a convergence of experience toward a range of options for bringing multifunctional agriculture into widespread practice in diverse settings by working with farmer-participatory approaches in combination with advanced science solutions (Zoundi et al., 2001; Rickert, 2004).

The *continuing role of traditional and local knowledge in AKST* for most of the world's small-scale producers in generating innovations that sustain individuals and communities also merits highlighting. Indigenous knowledge (IK) is a term without exact meaning but it is commonly taken to refer to locally bound knowledge that is indigenous to a specific area and embedded in the culture, cosmology and activities of particular peoples. Indigenous knowledge processes tend to be nonformal (even if systematic and rigorous), dynamic and adaptive. Information about such knowledge is usually orally transmitted but also codified in elaborate written and visual materials or artifacts and relates closely to the rhythms of life and institutional arrangements that govern local survival and wellbeing (Warren and Rajasekaran, 1993; Darré, 1999; Hounkonnou, 2001). Indigenous and local knowledge actors are not necessarily isolated in their experience but actively seek out and incorporate information about the knowledge and technology of others (van Veldhuizen et al., 1997). Sixty years' ago such knowledge processes were neglected except by a handful of scholars. From the 1970s onwards a range of international foundations, NGOs, national NGOs and CBOs began working locally to support IK processes and harness these in the cause of sustainable agricultural modernization, social justice and the livelihoods of the marginalized (IIRR, 1996; Boven and Mordhashi, 2002). Much more is known today about the institutional arrangements that govern the production of IK in farming (Colchester, 1994; Howard, 2003; Balasubramanian and Nirmala Devi, 2006). Poverty and hunger persist at local levels and among indigenous peoples and this indeed may arise from inadequacies in the knowledge capacity of rural people or the technology available but field studies of knowledge processes of indigenous peoples, their empirical traditions of enquiry and technology generation capabilities (Gonzales, 1999) establish that that these also can be highly effective at both farm (Brouwers, 1993; Song, 1998; Hounkounou, 2001) and landscape scales (Tiffen et al., 1994; Darré, 1995). IK related to agriculture and natural resource management is assessed today as a valuable individual and social asset that contributes to the larger public interest (Reij et al., 1996; Reij and Waters-Bayer, 2001; World Bank, 2006) and likely to be even more needed under mitigation of and adaptation to climate change effects.

However, empirical research shows how economic drivers originating in larger systems of interest tend to undermine the autarchic gains made at local levels or to block further development and upscaling (Stoop, 2002; Unver, 2005; van Huis et al., 2007). A major challenge to IK and more broadly to FPRE over the last few decades has been the emergence of IPR regimes (Hardon et al., 2005) (see 2.3.1) that so far do not adequately protect or recognize individual farmers' and communities' ongoing and historic contributions to knowledge creation and technology development or their rights to the products and germplasm created and sustained under their management. Even so, innovative ways forward can be found: formal breeders and commercial organizations in the globally important Dutch potato industry cooperate with Dutch potato hobby specialists in breeding and varietal selection; farmers negotiate formal contracts which give them recognition and reward for their intellectual contribution in all varieties brought to market.

The inequities in access and benefit sharing under the various protocols and conventions negotiated at international levels have given rise to a strong civil society response (2.2.1; 2.2.3) reflected in the Declaration on Indigenous Peoples' rights to genetic resources and IK - a collective statement on an international regime on access and benefit sharing issued by the indigenous peoples and organizations meeting at the Sixth Session of the United Nations Permanent Forum on Indigenous Issues, in New York on 14-25 May, 2007 (ICPB-Net Indigenous Peoples' Council on Biocolonialism, http://lists.ipcb.org/listinfo.cgi/ipcb-net-ipcb.org). Recent experience with the development of enforceable rights for collective innovations (Salazar et al., 2007) offers ground for evolution of currently dominant IPRs. There are new concerns that clean development mechanisms (CDMs), international payments for environmental services or payments for avoided deforestation and/or degradation will over-ride the rights of indigenous people's and local communities.

The final model considered here is by far the most dominant model of knowledge processes associated with commercial innovation in the private sector, *the chain-linked model* (Kline and Rosenberg, 1986). A distinctive feature is the effort made throughout every stage of product development to obtain feedback from markets and end users (Blokker et al., 1990); it is demand-driven rather than supply-push. It has given significant impulse to the development of market economies wherever the enabling conditions exist but has had little to offer where science organizations have remained weak and consumer markets are unable to articulate monetary demand – as in fact has been the case for much of the period among the rural and urban poor and especially among women and other marginalized peoples.

The recent emphasis among policy makers on developing market-oriented and market-led opportunities along entire value chains for small-scale producers and other rural people (DFID 2002, 2005; NEPAD, 2002; IAC, 2004; FAO, 2005c; UN Millennium Project, 2005; World Bank, 2005; OECD, 2006) has created wider interest in the model as a platform where diverse actors in public-private partnerships can find each other and organize their respective roles. Today it is being extended with varying energy mainly in the ‘new consumer economies’ i.e. countries with populations over 20 million (Argentina, Brazil, China, Colombia, India, Indonesia, Iran, Malaysia, Mexico, Pakistan, Philippines, Poland, Russia, Saudi Arabia, South Africa, South Korea, Thailand, Turkey, Ukraine, Venezuela). However, evidence of the extent to which small-scale producers can participate effectively, if at all, in these arrangements in the absence of strong producers’ organizations (Reardon et al., 2003) and of the impact on knowledge management (Spielman and Grebner, 2004; Glasbergen et al., 2007) has shown that the interests of private research and public-private partners may diverge from the combined public interest goals of equity, sustainability and productivity. Holding on to benefits may be difficult for employees and national research systems in globalizing markets as the recent rapid switch of a number of commercial cut flower operations from Kenya to Ethiopia illustrates, while global retailers’ ability to determine price, quality, delivery and indirectly also labor conditions for suppliers and producers in the chain means that the burdens of competition may be transferred to those least able to sustain them (Harilal et al., 2006).

### 2.1.3.1. New challenges and opportunities.

Transfer of technology has become important in recent years as a means of shifting technological opportunity and knowledge among private commercial actors located in different parts of the world and through science networks that stretch across geographic boundaries. It continues to guide practice as a means of promoting farm level change in what are still large public sector systems in countries such as China (Samanta and Arora, 1997). However, increasingly ToT has to find its place in an organizationally fragmented and complex context that emphasizes demand-driven rather than supply-push arrangements (Rivera, 1996; Leeuwis and van den Ban, 2004; Ekwamu and Brown, 2005). The shift toward contracting or other forms of privatization of research, extension and advisory services in an increasing number of countries (Rivera and Gustafson, 1991; Byerlee and Echevveria, 2002; Rivera and Zijp, 2002; van den Ban and Samantha, 2006) is an effort to re-organize the division of power among different players in AKST. In the process the central state is losing much of its ability to direct technological choice and the organization of knowledge processes. The effects and the desirability in different contexts of altering the balance between public and private arrangements remain under debate as the expanding diversity of financing and organizational arrangements has not yet been fully assessed (Allegri, 2002; Heemskerk and Wennink, 2005; Pardey et al., 2006a).

Decentralization and devolution of development-related governance powers from central to more local levels in an increasing number of developing countries has opened the space for many more instances of FPR&E in an increasingly diverse array of partnerships that are not easy to classify and demand new frames of understanding (Dorward et al., 1998; AJEA, 2000). At the same time, the push for export-oriented agriculture and in an increasing number of countries, the strong growth in domestic consumer demand has opened the space for the chain-linked model to be expressed more widely and with deeper penetration into small-scale farming communities. In addition, the 'core estate-with-out-growers' model has taken on new life as international food processors and retailers contract organized producer associations to produce to specification. The partnership between IFAD and the Kenya Tea Development Authority to introduce sustainable production techniques to small-scale outgrowers by means of Field Schools is a strong example of how changing values in consuming countries can have positive knock-on effects for the poor. Some models are more fit than others for meeting development and sustainability goals (Table 2-2).

INSERT Table 2-2. Characteristics of models of knowledge processes in relation to fitness for purpose.

The growing recognition of the complexity of knowledge processes and relations among a multiplicity of diverse actors has led to renewed attention to the role of *information and communication processes* (Rogers and Kincaid, 1981). All parties in communication play roles of "senders" and "receivers," "encoders" and "decoders," of information but communication typically is neither neutral nor symmetric: empirical studies demonstrate the extent to which social, cultural and political factors determine whose voices are heard and listened to (Holland and Blackburn, 1998). The history of the last sixty years may be read in part as a history of struggle to get the voices of the poor, of women and other marginalized people heard in the arenas where science and technology decisions are made (Leach et al., 2005; IDS, 2006).

By the 1980s the technologies of the digital age began to revolutionize the ability to obtain and disseminate information. Computer communication technologies and mobile telephony are becoming available to populations in developing countries (ITU, 2006). Mobile telephony by end 2006 had become a US$ 25 billion industry across Africa and the Middle East and Indian operators were signing up 6.6 million new subscribers a month. In the last five years low cost mobile telephony has begun to over-take computer-based technology as the platform for information-sharing and communication. For the first time, poor producers in remote places no longer have to remain isolated from market actors or to rely on bureaucrats or commercial middlemen for timely market information (Lio and Meng-Chun, 2006). Initiatives such as TradeNet (Ghana) connect buyers and sellers across more than ten countries in Africa and Trade at Hand provides daily price information to vegetable and fruit exporters in Burkina Faso and Senegal.

The new ICTs are also opening up formal education opportunities, ranging from basic literacy and numeracy courses to advanced academic, vocational and professional training. Free on-line libraries (e.g., IDRIS) and new institutional arrangements offer potential for further innovation in knowledge processes. For instance, the Digital Doorway, a robust portable computer platform with free software for downloading information, is being initiated at schools and community forums throughout southern Africa by Syngenta and the University of Pretoria to support locally adapted curricula for Schools in the Field covering a range of crops, animals, poultry, small rural agroenterprises and soil and water management. Insufficient information is available as yet to make robust assessments of these trends but the early evidence is that their impact may be at least as important as technologies originating within AKST development. Nonetheless, the rate of expansion of access to modern ICTs continues to be much greater in developed than developing countries and among urban more than rural populations, raising concerns about how to avoid ICTs reinforcing existing patterns of inequality (Gao and Li, 2006).The history of broadcast radio suggests that over time the “digital divide” may become narrower. Issues of the quality and relevance of the information available are likely to become more important than those of access and ability to use the technology.

### *2.1.3 Science processes*

Science processes are those involved in the creation and dissemination of scientific knowledge; including processes within the scientific community and interactions between scientific communities and other actors. Members of a scientific community are defined here as those who are principally involved as professional actors in such activities as pre-analytic theorizing, problem identification, hypothesis formulation and testing through various designs and procedures (such as mathematical modeling, experimentation or field study), data collection, analysis and data processing and critical validation through peer review and publication, i.e. activities commonly viewed as core practices of scientists.

Intellectual investment in these activities by individual scientists is driven in part by human motivations such as curiosity and the pleasure of puzzle-solving but also by the structure of professional incentives that encourages - even demands - that scientists pay closer attention to obtaining the recognition of their work by peers in the scientific community rather than by other segments of society. However, scientific institutions cannot ignore the preoccupations and knowledge wielded by other actors (Girard and Navarette, 2005) and in other societal forums. This is particularly obvious in the case of agriculture; no matter the science involved in the origin and initial development of an idea, to be effective it has to become an applied science with potential for wide impact whose results are visible to all in the form of changes in agricultural landscapes. Thus it is unsurprising that opinions and drivers outside the domain of science itself condition science for agriculture. This tension between the incentives faced by individual scientists and the societal demands placed on scientific institutions in agriculture has been growing in recent decades, posing a strong challenge for the governance of scientific institutions (Lubchenco, 1998).

#### 2.1.3.1 Cultures of science

Agricultural science processes in our period have been associated with the cultures of thought distinguished by two intellectual domains known respectively as ‘positivist realism’ and ‘constructivism’. The positivist realist understanding of modern science as a neutral, universal, and value-free explanatory system has dominated the processes of scientific inquiry in agriculture for the period under review. The basic assumptions are that reality exists independently of the human observer (realism), and can be described and explained in its basic constitution (positivism).This mind set is legitimate for the work that professional scientists do and enables transparent and rigorous tests of truth to guide their work. However, others (Kuhn, 1970; Prigogine and Stengers, 1979; Bookchin, 1990; Latour, 2004) have found this scheme problematic for explaining causality in their own disciplines for a number of reasons: it appears to exclude the qualitative (even if quantitative) ambiguous and highly contextualized interpretations that human subjects give to the meaning of reality and it does not allow sufficiently for the unpredictability of the social effects of any intervention nor for the reflexive nature of social interactions (the object of enquiry never stabilizes; learning that something has happened changes decisions about what actions to take, in an unending dance of co-causality). This difference in legitimate perspective provides a partial explanation of why ‘the history’ of the last sixty or so years cannot stabilize around a single authoritative causal interpretation of what has happened.

For scientists working within positive realist traditions the locus of scientific knowledge generation is largely confined to public and private universities, independent science institutions and laboratories and to an increasing extent corporate research and development (R&D) facilities. These offer the conditions for highly specialized expertise to be applied to study of immutable laws governing phenomena that allow for prediction and control. Technology is conceived in this logic as applied science, i.e. as a design solution developed by experts removed from the site of application. The main task of the agricultural sciences in this perspective thus becomes that of developing the best technical solutions to carefully described problems (Gibbons et al. 1994; Röling, 2004). The problem description can and often does include scientists' understanding of environmental and social dimensions.

The paradigm of positive realism has attracted large-scale support for public and private science institutions as a way of thinking about and organizing innovation in tropical agriculture. It was harnessed to the expectation of maximizing yields and compensating for shortfalls in the quantity or quality of the biotic and abiotic factors of production by the provision of supplementary inputs, such as fertilizers and services to improve the productivity of labor and land. As such this paradigm lies at the heart of what is often called 'productivism', a doctrine of agricultural modernization giving primary emphasis to increased productivity rather than the multifunctionality of agriculture or to the role of agriculture in rural development. It has constituted for much of the period under review a primary justification for science investments for development (Evenson et al., 1979).

The dominance of this paradigm has had notable institutional consequences. University agricultural faculties progressively became divided into highly specialized departments. This split created 'knowledge silos' that reflected the increasing specialization of scientific disciplines that reduced agriculture as an integrated practice into smaller and smaller fractions that largely excluded the human manager. This reductionism made it harder to mobilize multidisciplinary teams to address more complex problems or (Bentley, 1994) and was consistent with the increasing specialization in modern farm sectors, developing countries and the social sciences.

More inclusive and integrated science practices began to emerge from the 1970s onwards (Werge, 1978; Agarwal, 1979; Izuno, 1979; Biggs, 1980, 1982; Rhoades, 1982; Biggs, 1983). The drivers for this included the emergence of gender studies and women in agricultural development projects (Jiggins, 1984; Appleton, 1995; Doss and McDonald, 1999); the impact studies, analyses, and evaluations commissioned through the reporting cycles of the UN Human Development agency and the FAO's Food and Hunger  reports that showed the persistence of widespread hunger, rural unemployment and food insecurity for vulnerable populations; and studies of the land degradation, water pollution, and loss of flora or fauna species associated with narrow technological interventions. (Repetto, 1985; Loevinsohn, 1987; Reptto et al., 1989; Repetto, 1990). The growing experience of alternative ways of mobilizing science capacity (noted in 2.1.2 -2.1.4) complemented these efforts and stimulated a more critical reflection within scientific communities (ODI, 1994) on the governance of agricultural science and the accountability of science as a source of innovation not only for ‘success’ but also for ‘failure’ in agricultural development. Institutional responses included the creation around 1995 of a system-wide program on gender analysis and participatory research within the CGIAR and the beginning of the sustained long term research that fed into the Millennium Ecosystem Assessment (MA, 2005).The ethical and political questions posed by scientific and technological choices stimulated the spread and more rigorous use of ethics committees to address a broader range of societal considerations and renewed efforts to bring together the natural, technical and social sciences. This often involved the creation of specialist cross-disciplinary organizational units charged with the task of integration around selected themes and of new knowledge networks.

Scientists trained to specialize often struggled to understand their role in these arrangements. A different paradigm, constructivism, offered a sound epistemological base for the kinds of interactive and integrative work that challenged scientists as professionals to think about themselves and their work in new ways. The epistemological position of constructivism is that reality and knowledge are actively created through social relationships and through interactions between people and their environment. These relationships and interactions are seen as affecting the ways in which scientific knowledge is produced, organized and validated (Schütz, 1964; Berger and Luckmann, 1966). An authoritative overview of empirical research studies (Biggs and Farrington, 1991) robustly demonstrated the ways in which institutional and political factors affected both the conduct of agricultural science and the translation of research results into farming practices. An important distinction became more widely understood: i.e. between knowledge as a lived experience of inquiry and hence transient and continuously re-created and knowledge products that can be stabilized (e.g., in journal articles, technologies, artifacts and in the norms of organizational behavior) and shared and under the right conditions, will diffuse. It opened the door to science not only as a *source* of innovation but as potentially a *co-creator of knowledge* in processes of enquiry shared with other actors (Borrini-Feyerabend, et al., 2004).

Collaboration among science disciplines tended to assume one of three forms: combining multiple disciplines in a single study; to a variable extent dissolving disciplinary boundaries in purposive learning from each others’ disciplines and non-science actors; and transdisciplinary effort that actively sought to build new frames of meaning and understanding (Fig. 2-2). The founding precepts of General Systems Theory, introduced by the biologist von Bertalanffy in 1950 informed these efforts, especially from the 1970s onwards (Spedding, 1975; Cox and Atkins, 1979; Altieri, 1987). Strong interdisciplinary collaboration in developing systemic approaches to agroecology occurred throughout the world in the 1980s, often led by NGOs. The boundaries expanded to include on-farm fisheries, the role of wild and semi-domesticated foods and medicines (Scoones et al., 1992), forests and non-timber forest products (Ball, Carl, and Del Lungo, 2005). The agricultural sciences were newly positioned at the interface of two complex and complementary systems: natural and social systems. Translation of this understanding into practice nonetheless faced strong barriers within the scientific community and from market specialization and the dominance of economic drivers over social and ecological sustainability concerns.

**INSERT Fig. 2-2.** Modes of science.

### 2.1.3.2 A changing contract between science and society

In the immediate post World War II period in what later became grouped as OECD countries there was a tacit understanding between science and society that what was good for science was good for humanity and that science would deliver solutions to societal problems. The output response in OECD agricultures and under the Green Revolution's early successes in Asia and then Latin America consolidated this view and led over time to significantly higher national investments in AKST and science in general. The less strong impacts experienced in sub-saharan Africa (Beintema and Stads, 2006) reflected both the weakness of the scientific infrastructures and personnel around the time of independence and the overall economic and social conditions of the time, leading to a prolonged period of donor investment to strengthen capacity (see Chapter 8). Although a few 'islands of success' were created the lack of sustained national investments meant that the capacity for science and technology development at the university, research institute or enterprise level in most of sub-Saharan Africa by the 1990s had fallen to an exceptionally low level (Eisemon, 1986; Eisemon and Davis, 1992; Gaillard and Waast, 1992). Recent renewed efforts by African leaders to build a stronger contract between their societies and science have not yet translated into adequate national investments in their own science base.

Over time science as a human activity began to be viewed more critically as the increasing reliance on science and technology to drive national economic growth progressively revealed also the technical risks of scientific development. This view resulted in a growing public mistrust in some countries concerning the effectiveness of science as the unqualified promoter of the public good, (Nelkin, 1975; Calvora, 1988; Gieryn, 1995; BAAS, 1999) although in others, such as Sweden, public confidence in science has remained high. For example, public concerns, themselves informed by science, surfaced for instance concerning the impact of synthetic chemicals on other species, human health and the environment. As these issues began to figure more strongly in agricultural and food science research priorities (Byerlee and Alex, 1998) science began to occupy an ambiguous position as a supplier of the objective knowledge needed to generate new kinds of formal knowledge and technology as well as that needed to identify and measure risks and the evidence of harm that applications of knowledge and technology might cause in particular conditions of use; science as a human activity thus became implicated in societal controversies (Nash, 1989; Brimblecombe and Pfister, 1993; Gottlieb, 1993; Sale, 1993; Shiva, 2000; Maathai, 2003). It experienced both optimistic support from the public about its potential social utility and loss of credibility when it was found in specific instances to have produced unintended or undesirable results. At the same time, the lines between public good science, not for profit science and science carried out for commercial gain began to blur as the public sector in many countries began to yield its role as a direct supplier and the private commercial sector emerged as a major source of funding for agricultural science and technology development.

The imbalance between science investments, infrastructures and staffing in OECD countries compared to tropical countries (UNESCO, 1993; Annerstedt, 1994) for much of the period meant that 'science's contract with society' for the goals of international agricultural development and sustainability had to be mobilized with the support of OECD country electorates. That is, the resources had to be mobilized by appeals to values and interests of people distanced from those experiencing the effects. This process stimulated the growth of civil society and NGOs working on international development and the introduction of the broader concerns of citizens into the science agenda. As science institutions by the 1990s in the poorest developing countries became heavily dependent on foreign funding and foreign training opportunities the concerns of donors tended to drive their agendas. Other countries such as Brazil, South Africa, China and India identified S&T as key drivers of their own economic development while giving relatively lower attention specifically to the agricultural sciences. Private commercial investment in science tended to concentrate on technologies such as food preservation and processing, pest control technologies, feed stuffs, veterinary products and more recently also on transgenic crops for which profits could be more easily captured (Clive, 1999); under competitive commercial pressures the concerns of better-off consumers and urban residents also began to influence the AKST agenda.

As a consequence of these complex inter-weaving trends, public support for international agricultural development and sustainability was and remains peculiarly susceptible to crises (EC, 2001; 2005). These include crises in intensive agricultures, in the public mind in Europe associated with 'the silent spring' (Carson, 1962) or diseases such as BSE (bovine spongiform encephalopathy - "mad cow disease") and more recently the risks of the spread of avian flu to the intensive poultry industries of Europe and beyond. The actual or potential human health consequences provided an extra emotional dimension. Environmental crises, such as the drying of Lake Aral through diversion of its waters to feed the Soviet Union's cotton farming or the unsustainable use of surface and groundwater in irrigated farming in the southwest of the United States or in the Punjab or crises of acute hunger and starvation, drought or flooding similarly brought the agricultural sciences into question. Fear of the unknown and suspicion of the concentration of ownership in commodity trading, food industries and input supply (Tallontire and Vorley, 2005) and increasing private control over new opportunities in agriculture arising from advances within science (WRI/UNEP/WBCSD, 2002) also fed into public concerns. The first generation technologies resulting from genomics e.g., raised concerns about the risks of increased spread of known allergens, toxins or other harmful compounds, and horizontal gene transfer particularly of antibiotic-resistant genes and unintended effects (Ruan and Sonnino, 2006). An important consequence is that demand has grown for stronger accountability, stricter regulation and publicly funded evaluation systems to determine objectively the benefits of new sciences and technologies.

Today in many industrialized countries an increasing percentage of the funding for university science comes from private commercial sources. It tends to be concentrated in areas of commercial interest or in advanced sciences such as satellite imaging, nanotechnologies and genomics rather than in applications deeply informed by knowledge of farming practice and ecological contexts. License agreements with universities may include a benefit sharing mechanism that releases funds for public interest research but product development, especially the trials needed to satisfy regulatory authorities, is expensive and companies (as well as universities) need to recover costs. Hence a condition of funding often is that the source of funds determines who is assigned first patent rights on faculty research results. In some cases the right to publication and the uninhibited exchange of information among scholars are also restricted. The assumption under these arrangements that scientific knowledge is a private good changes radically the relationships within the scientific community and between that community and its diverse partners

### *2.1.4 Technology and innovation processes*

The relationship between technology and innovation has remained a matter of debate throughout the period under review. The analysis by scholars around the world of literally thousands of empirical studies of the processes that have led to changes in practice and technology (not only in agriculture but in related sectors such as health) over time has forced acceptance that innovation requires much more than a new technology, practice, or idea and that not all change is innovation. Innovation processes have been driven mainly by for-profit drivers but there has been also an as yet incomplete convergence toward AKST relationships, arrangements and processes that foster innovations supportive of socially inclusive and ecologically sustainable and productive agricultures.

### 2.1.4.1 Changes in perspective: from technologies to Innovations

The proposition that technical change could be a major engine of economic growth was demonstrated in the 1950s (Solow, 1957). Later analysis of empirical evidence showed that small-scale producers, although handicapped by severe constraints, made rational adaptations over time in their practices and technologies in response to those constraints. In as far as externally introduced technology released some of the constraints, technology could become a driver of significant change (Schultz, 1964). The Green Revolution subsequently appeared to vindicate the analysis and it quickly became dominant in the agricultural economics profession (Mosher, 1966).The model that this analysis pointed toward is the dominant way of organizing knowledge and diffusion processes, i.e. 'the transfer of technology model' (2.1.2) (e.g. Chambers and Jiggins, 1986). It is known also as a policy model, variously as 'the agricultural treadmill' (e.g. Cochrane, 1958) and 'the linear model' (e.g. Kline and Rosenberg, 1986); and its role in policy is assessed here. In its simplest form it recommends *technology supply-push,* i.e., developing productivity enhancing component technologies through research for delivery, transfer, or release to farmers, the 'ultimate users'.

The model emerged in a specific historical context, the American mid-West in the decennia after WWII (Van den Ban, 1963); similar models were elaborated from empirical findings in other economic sectors. Although these mechanisms driving the model's impact are familiar to economists they are not necessarily as familiar to others so the persistence of technology supply push as the dominant policy model for stimulating technology change in agriculture warrants a full explanation of the mechanisms. In the case of agriculture the empirical data robustly confirm the following features:

1. *Diffusion of innovations*. Some technologies diffuse quite rapidly in the farming community after their initial release, typically following the S-curve pattern of a slow start, rapid expansion and tapering off when all farmers for whom the innovation is relevant or feasible have adopted. The classic case is hybrid maize in Iowa (Ryan and Gross, 1943). Diffusion multiplies the impact of agricultural research and extension effort 'for free'. But diffusion is mainly observed ex-post: it is difficult to predict (or ensure) that it will take place (Rogers, 2003).
2. *Agricultural treadmill*. The treadmill refers to the same phenomenon but it focuses on the economics (Cochrane, 1958). Farmers who adopt early use of a technology that is more productive or less costly than the prevailing state-of-the-art technology, i.e. when prices have not as yet decreased as a result of increased efficiency, capture a windfall profit. When

others begin to use the new technology, total production increases and prices start to fall. Farmers who have not yet adopted the technology or practice experience a price squeeze: their incomes decrease even if they work as hard as before. Thus they must change; the treadmill refers to the fact that the market propels diffusion: it provides incentives for early adoption and disincentives for being late.

3. *Terms of trade*. A key underlying aspect of the treadmill is that farmers cannot retain the rewards of technical innovation. Because none of the thousands of small firms who produce a commodity can control the price, all try to produce as much as possible against the going price. Given the low elasticity of demand of agricultural products, prices are under constant downward pressure. During the last decennia, the price of food has continuously declined both in real and relative terms (World Bank, 2008). The farm subsidies in the US and Europe can be seen as a necessary cost for societal benefit without rural impoverishment.
4. *Scale enlargement*. In the tail of the diffusion process, farmers who are too poor, too small, too old, too stupid or too ill to adopt eventually drop out. Their resources are taken over by those who remain and who usually capture the windfall profits. This shakeout leads to economies of scale in the sector as a whole.
5. *Internal rate of return*. Investing in agricultural research and extension to feed the treadmill has a high internal rate of return (Evenson et al., 1979). The macro effects of relatively minor expenditures on technology development and delivery are major in terms of (a) reallocating labor from agriculture to other pursuits as agriculture becomes more efficient, (b) improving the competitive position of a country's agricultural exports on the world market, and (c) reducing the cost of food. An advantage is that farmers do not complain. Their representatives in the farmers' unions are among those who capture windfall profits and benefit from the process, even though in the end the process leads to loss of farmers' political power as their numbers dwindle to a few percent of the population. The treadmill encourages farmers to externalize social and environmental costs, which tend to be difficult to calculate and hence usually are not taken into account. One may note here that this process, first described at the national level in the case of the USA, also explains the growing gap in the productivity of agricultural labor between industrialized and developing countries and that it leads to overall efficiencies in production and reduced prices for consumers, outcomes that have favored its persistence as a dominant policy model.

However, other business analysts and social scientists throughout the period under review have stressed the concept of innovation rather than mere technical change as a measure of development. The evidence that technical change itself requires numerous often subtle but decisive steps before an adoption decision is made reinforced this view (Rogers, 1983). Others pointed to biophysical, sociocultural, institutional and organizational factors such that when the same technology is brought into use in different contexts the effects vary (Dixon et al., 2001). Recently more emphasis has been given to development of ‘best fit’ technology options for a given situation, reflecting further discoveries of institutional and sociological factors that shape technical opportunities (Herdt, 2006; Ojiem et al., 2006). This understanding has deep roots in extension research (e.g. Loomis and Beagle, 1950; Ascroft et al., 1973; Röling et al., 1976), farming systems research (Collinson, 2000), 1980s gender research (e.g. Staudt and Col, 1991; Sachs, 1996), and 1990s policy research (e.g. Jiggins, 1989; Christopolos et al., 2000). However, the reasons that thinking about policy began to change likely had little to do with this research and more to do with the realization that technology supply-push could fuel massive social problems wherever there were no alternative opportunities for those who could not survive in farming. This lack of survival contributed to the growth of megacity slums (UN Habitat, 2007), the ease with which displaced youngsters eager turned toward civil disorder and even civil war (Richards, 2002; UNHCR, 2007) and the growing numbers of internal and transboundary migrants (UNHCR, 2007; UN Population Fund, 2007). Supply-push arrangements were shown to produce agricultures accounting for 85% of the world’s water withdrawals and 21% (rising to 35%) of gaseous emissions contributing to climate change; and to the declining material condition of natural resources and biophysical functioning (MA, 2005; UNEP, 2005). The cumulative evidence indicated a policy change was overdue.

The concept of innovation systems offered itself as a policy model for sustaining agricultures to meet ecological and social needs. Effective innovation systems were shown to need systemic engagement among a diversity of actors (Havelock; 1986; Swanson and Peterson, 1989; Röling and Engel, 1991; Bawden and Packham, 1993; Engel and Salomon, 1997; Röling and Wagemakers, 1998; Chema et al., 2003; Hall et al., 2003, 2006). However, people and organizations interact in diverse ways for the purposes of creating innovation for sustainable development; the range of actors needed to develop a specific innovation opportunity is potentially large and thus becomes increasingly difficult to classify (Fig. 2-3) (see 2.3). The ‘innovation systems’ concept, widely used in other industries, usefully captures the complexity (Hall et al., 2006) by drawing attention to the totality of actors needed for innovation and growth; consolidating the role of the private sector and the importance of interactions within a sector, and; emphasizing the outcomes of technology and knowledge generation and adoption rather than the strengthening of research systems and their outputs.

Empirical studies emphasize that the dominant activity in the process is working with and re-working the stock of knowledge (Arnold and Bell, 2001) in a social process that is realized in collaborative effort to generate individual and collective learning in support of an explicit goal. Innovation processes focus on the creation of products and technologies through ad hoc transformations in locally specific individual or collective knowledge processes. As such innovation is neither science nor technology but the emergent property of an action system (Crozier and Friedberg, 1980) in which knowledge actors are entangled. The design of the action system thus is a determinant of the extent to which an innovation meets sustainability and development goals.

#### 2.1.4.2. Market-led innovation

From about the 1990s onwards innovation processes in agriculture principally have been driven by a rise in market-led development. Typical responses to market pressures in North America and Europe in terms of the way in which technical requirements, market actors, and market institutions interact can provide an understanding of the 'innovation space' for socially and ecologically sustainable agriculture (NAE Chap 1; Fig. 2-3).

**INSERT FIG. 2-3.** Elements of an agricultural innovation system.

#### 2.1.4.3. Technological risks and costs in a globalizing world

The risk outlook fifty years ago could be described in general terms as high local output instability, relative autonomy of food systems and highly diverse local technology options: an agricultural technology that failed in one part of the world had few consequences for health, hunger or poverty in other regions. The increase in aggregate food output and the trend toward liberalizing markets and globalizing trade has smoothed out much of the instability; it has integrated food systems (mostly to the benefit of poor consumers) and it has spread generic technologies throughout the world for local adaptation. The mechanisms of food aid, local seed banks and other institutional innovations have been put in place to cope with catastrophic loss of entitlements to food or localized production shortfalls. Yet the world faces technological risks in food and agriculture that have potential for widespread harm and whose management requires the mobilization of worldwide effort (Beck et al., 1994; Stiglitz, 2006). A robust conclusion is that human beings are not very good at managing complex systemic interactions (Dörner, 1996). Immediate costs of risks that cause harm typically are carried by the poor, the excluded and the environment, for instance with regard to choices of irrigation technologies (Thomas, 1975; Biggs, 1978; Repetto, 1986); crop management (Repetto, 1985; Kenmore, 1987; Loevinsohn, 1987); and natural resource and forestry management (Repetto et al., 1989; Repetto, 1990; Repetto, 1992; Hobden, 1995). The weight of the evidence is that power relations and pre-analytic assumptions about how institutions and organizations actually work in a given context shape how scientific information and technologies are developed and used in practice, producing necessarily variable and sometimes damaging effects (Hobart, 1994; Alex and Byerlee, 2001). Recent assessments for instance of the 'long shadow' of livestock farming systems (Steinfeld et al.,

2006) and of agricultural use of water (Chapagrain and Hoekstra, 2003) lead to a well-founded conclusion that estimations of agricultural technologies' benefits, risks and costs have been in the past too narrowly defined. The mounting scale of risk exposure in agriculture is delineated in the Millennium Ecosystem Assessment (2005), Global Water Assessment (2007), and IPCC reports (2007).The accumulating weight of evidence that past technology choices in agriculture have given rise to unsustainable risks has led to efforts to develop more appropriate technological risk assessment methods (Graham and Wiener, 1995; Jakobson and Dragun, 1996; NRC, 1996) and to take on differing perspectives on what levels of harm are acceptable and for whom (Krimsky and Golding, 1992; Funtowicz and Ravetz, 1993; Funtowicz et al., 1998; Scanlon, 1998; Stagl et al., 2004). Important experience has been gained in working with civil society on technological risk assessments and sustainability appraisals, sometimes involving large numbers of citizens (Pimbert and Wakeford, 2002; IIED, 2006; Pimbert et al., 2006).

## 2.2 Key Actors, Institutional Arrangements and Drivers

Actors and institutions have power to set policy agendas and influence how research and development investments are made. All knowledge actors develop processes for generating AKST and innovation that evolve within their own IAs and culture of understanding. These processes can generate stress when key actors are excluded or marginalized by new or old arrangements (Table 2-3).

INSERT Table 2-3. Analytic map of the main features of AKSTD paradigms.

The main actors considered here are in the vast majority *farmers and farm laborers,* many of whom are poor, with limited access to external resources and formal education, but rich in traditional and local knowledge and increasingly organized and adept at sharing knowledge and innovating. A*dditional domestic actors* affecting the development and innovation of AKST include local, provincial and national governments, and the agencies, departments and ministries devoted to agriculture, environment, education, health, trade, finance, etc. Still *other actors* with direct impacts on AKST include regional consortia and international institutions, FAO, the Global Integrated Pest Management (IPM) Facility, the World Bank, CGIAR, private foundations, and others. Each organization develops and brings its own sets of priorities, perspectives and agendas to the business of AKST. Private sector actors who have played increasingly important roles are commercial and corporate players and civil society organizations (CSOs), including farmer and consumer organizations, foundations and those working for nonhuman species and the environment, as well as a range of development and relief NGOs.

The currently dominant AKST systems are the product of a long history of attempts by diverse combinations of these actors, under numerous institutional arrangements (IAs), to meet the needs and challenges of agriculture in different contexts, as well as the actors' own individual or institutional needs. Their histories are made up of successes, but also failures and frustrations, often leading to new attempts at meeting both local and global challenges. In many instances, crises have led to the emergence of new actors and the reshuffling of roles and relationships. Institutional arrangements formally or informally coordinate the work of knowledge producers and engage them in distinctive knowledge processes, thus favoring the emergence of different kinds of innovation. Some become long-standing permanent arrangements; others are *ad hoc* initiatives or of more recent origin.

### *2.2.1 Farmer and community-based arrangements*

The emergence of major producer organizations representing their members' interests and rights at district, national, regional and international levels may be seen as an increasingly strong driver of change over the last decades. Most of them are actively engaged in the provision of technology and information services and have entered into partnerships with R&D providers. Many now have websites that act as an information umbrella for and communication link to thousands of affiliated farmers' groups organized at local levels. Examples include the Network of Farmers' Organizations and Agricultural Producers from western Africa (http://www.roppa-ao.org); the International Land Coalition (www.landcoalition.org/partners/partact.htm); the International Federation of Agricultural Producers (www.ifap.org); and Peasants Worldwide (www.agroinfo.nl/scripts/website.asp).

The focus on local mobilization masks the wide scale of effort and impact (Boven and Mordhashi, 2002). For example, in 2004 Catholic Relief Services was working directly with 120,000 poor producers in community-based seed system development (www.crs.org) and South East Asian Regional Initiatives for Community Empowerment (SEARICE) (see 2.2.3). The local seeds movement pioneered by such organizations has given rise to information exchange networks that assert individual and community rights to 'first publication' so as to safeguard native IPR and germplasm. Over time, such organizations have strengthened their own R&D networks by commissioning research and through organizing national and international technical conferences, such as the International Farmers' Technical Conference held in conjunction with the 2005 Convention on Biodiversity meeting.

*Farmer research partnerships* typically bring together farmers, professors, scientists and researchers to compose a technical pool of expertise dedicated to collaboration with farmers in research and development. These IA's emphasize the centrality of primary producers, food processors and laborers in agricultural and food systems. In general, they initially capitalize volunteerism and fund-raising activities to implement farmer-led projects, but often move on to a holistic approach to development of livelihoods and welfare, community empowerment and measures to extend farmer control over agricultural biodiversity. For instance, MASIPAG (Farmer-Scientist Partnership for Development, Inc.) was established in the Philippines in 1987, after more than five years' collaboration between farmers concerned about the negative impacts of high-yield rice and associated technologies on their livelihoods, local genetic resources, and environment, and a few progressive scientists. It then rapidly developed into a large farmer-led network of people's organizations, NGOs and scientists, promoting the sustainable use and management of biodiversity through farmers' control of genetic and biological resources, agricultural production and associated knowledge based on a strategy of placing command of the skills and knowledge of the agronomic sciences in the hands of small-scale producers. By 2004, MASIPAG was working with four national/regional civil society networks and organizations, seven Philippino universities and research centers and seven local government authorities and line agencies. MASIPAG's network of trial and research farms included 72 in 16 provinces in the island of Luzon, 60 in 10 provinces in Visayas and 140 in 14 provinces in Mindanao. MASIPAG today is recognized world-wide as a leading example of highly effective farmer-led and largely farmer-funded and farmer-managed, R&D and extension that is building small-scale farm modernization, resource conservation and food sector development on ecological principles (Salazar, 1992; Araya, 2000). At the other end of the spectrum, systematic testing has been carried out of user involvement in the barley breeding cycle in Syria (Ceccarelli et al., 2000). The researchers initially designed four types of trials: by farmers in their fields, with farmers on-station, by breeders in farmers' fields and by breeders on-station. Their experience of the rigor, reliability, and comparative costs and benefits of the four led them to concentrate on testing and selection by farmers in their own fields, complemented by seed multiplication on station. Similar achievements have been recorded in southwest China for maize (Vernooy and Song, 2004).

*Local research and innovation: the contribution of occupational education.* Local level innovation can be promoted if appropriate investments are made in educating farmers but this has been a relatively neglected area. One of the major breakthroughs has been the development and spread of *Farmer Field Schools* (FFS) (Braun et al., 2005). Based on adult education principles, the schools take groups of farmers through field-based facilitated learning curricula organized in cycles of observation, experimentation, measurement, analysis, peer review and informed decision-making. FFSs are making in aggregate a significant and influential contribution to sustainable and more equitable small farm modernization, particularly in the rain fed areas where two-thirds of the world's poor farm households live. Kenya, Tanzania and Uganda have included the approach in national research and extension strategies, as has India. Systematic review of available impact data (Braun et al., 2006; van den Berg and Jiggins, 2007) and area-based impact studies (Braun et al., 2002; Pontius et al., 2002; Bunyatta et al., 2005; Mancini, 2006) demonstrate positive to strongly positive achievements. Contributing effectively to farmer empowerment also contributes to the strengthening of civil society and self-directed development (Mancini et al., 2007). Others have criticized their cost in relation to the scale of impact (Quizon et al., 2000; Feder et al., 2004ab), noted the weak diffusion of specific technologies, lack of diffusion of informed understanding (Rola et al., 2002) and failure in some instances to develop enduring farmer organizations (Bingen, 2003; Tripp et al., 2005). Further experimentation is warranted to test if combining farmer education such as FFSs with complementary extension efforts will overcome the perceived shortcomings (Van Mele and Salahuddin, 2005).

World Learning for International Development, the Alaska Rural Systemic Initiative project and the Global Fund for Children similarly have documented gains (World Bank, 2005a) in the effectiveness and efficiency of local research, school-based science education and the development of agroecological literacy at the grass roots brought about by investing in farmers' occupational education (Coutts et al., 2005).

*Farmer-funded R&D and extension.* Innumerable examples exist of effective technological advances pioneered by farmers themselves; e.g., grafting against pests, biological control agents such as the golden ant in citrus in Bhutan (Van Schoubroeck, 1999) and soil management and farming system development in the Adja Plateau, Benin (Brouwers, 1993).Yet the economic value of local and traditional innovations has not been much researched. One study in Nigeria in the early 1990s estimated the contribution of the informal agricultural sector where farmers are using mostly indigenous innovations at about US $12 billion per year, providing income for an estimated 81 million people (ECA, 1992). This estimate, however, does not include the cost of opportunities foregone or traditional practices that do not work. Recent literature begins to sketch out the strengths and weaknesses that might be taken into account if a more comprehensive cost-benefit analysis were to be attempted (Almekinders and Louwaars, 1999).

### ***2.2.2 Producers of AKST at national level***

Countries have developed a complex array of public institutions, IAs and actors responsible for planning, funding, implementing, assessing, and disseminating public interest agricultural research. They include national, regional/municipal agricultural research institutions, universities and other higher education institutes and extension services. Most of these arrangements historically have been publicly financed because agricultural research investments involve externalities, and are subject to long gestation periods (cfr. Chap 8, Table 8.1; Lele and Goldsmith, 1989; Beintema and Stads, 2006; Pardey et al., 2006ab).

In the 1960s and 70s National Agricultural Research Systems (NARS) in developing countries (subchapter 2.1), especially agricultural research institutes (ARIs), received strong financial support from governments and international donors to launch agricultural modernization through the dissemination of Green Revolution technologies (Chema et al., 2003). In the 1980s, as a result of budgetary crises and adjustment programs, public funds for agricultural research failed to keep up with expanding demand. Public expenditure declined as proportion of total research and development spending; expenditure per researcher declined much more because staffing continued to expand faster than budgets. From the 1980s onwards, the main drivers of institutional development of the NARS were structural reforms in national economies and adjustment policies, global political changes; ideological demands for reduced public sector involvement and intervention; a greater private sector role and significant biotechnological breakthroughs (Byerlee and Alex, 1998; Iowa State Univ., 2007). These events have given rise to a diverse institutional landscape responding to both domestic and global priorities and opportunities. Brazil's EMBRAPA, for instance, has become an exporter of capacity, in 2007 opening liaison offices in West and East Africa whereas NARS in sub-Saharan Africa continue to face many constraints (Jones, 2004).

*Sub-Saharan Africa's National Research Systems*. Overall budget constraints throughout the period have weakened public sector NARS in most African states. The general panorama today is of deep attrition of human resources, equipment facilities, capital funding and revenue, despite islands of promise such as the revitalization of capacity in Uganda under vigorous decentralization policies, in Ghana in relation to agroindustrial developments and in post-apartheid South Africa. Nongovernmental organizations, the CGIAR, private commercial actors and recently the establishment of sub-regional bodies (Central African Council for Agricultural Research and Development, CORAF), (Association for Strengthening of Agricultural Research in Eastern and Central Africa, ASARECA) and similar arrangements for southern Africa supported by the Forum for Agricultural Research in Africa (FARA), have filled the gaps only in part. An alliance largely funded by a US-based philanthropic trust recently has been established to transfer germplasm and advanced biotechnology skills to African NARS to catalyze Africa's 'rainbow revolution.' Agricultural research trust funds set up to lever matching research contracts from commercial enterprises, donors and government organizations, have not succeeded; although farmer-managed funds are meeting with some modest success.

*The Agricultural Research Council (ARC) model*. Some large countries with complex research systems have established agricultural research councils to coordinate the work carried out at research institutes. The ARC typically is a public body which has – *inter alia* - the functions of managing, coordinating or funding research programs. Management of the councils has proved effective because they are both autonomous and accountable to users and donors for planning and executing research. In India, the Indian Council of Agricultural Research (ICAR) has coordinated the higher agricultural education system since the 1950s and in 1996 established an agricultural education accreditation board (http://www.icar.org.in/aeac/ednac.htm). In Africa, the role of ARCs has varied widely as some have moved beyond a policy and coordinating role to undertake research themselves (Bingen and Brinkerhoff, 2000). However, the councils that have proliferated have failed to live up to expectations, become bureaucratized (Chema et al., 2003) and been unable to influence national research budgets or coordinate agricultural research among institutions to reach out to small-scale farmers (Byerlee, 1998; Rukuni et al., 1998; Bingen and Brinkerhoff, 2000).

*The National Agricultural Research Institute (NARI) model*. This model is common in Latin American countries, where agricultural research has been conducted primarily at the national level. They control, direct and manage all publicly funded agricultural research; they may be autonomous or semiautonomous in budgetary support, scientist recruitment, financial norms and disciplines with experiment stations as the basis for research organization. Their creation in the 1950s and early 1960s was driven mainly by the recognition of the leading role of technological change in the modernization of agriculture. In the late 1990s, rural development and poverty alleviation efforts became differentiated from research and technology development, accompanied by the increasing participation by private sector entities in financing and implementing R&D activities. These shifts were driven by changes in the wider socioeconomic and political context within which the NARIs operated (i.e., state reform, deregulation, economic liberalization), and changes in the scientific processes underlying agricultural research (i.e., privatization of knowledge, plant breeders´ rights, patent protection for R&D results. In Latin America, two important constraints have limited the role of the NARIs: the decline in government funding and the weak incentives for coordination and cooperation among research system components within each country. In two cases the NARIs also had responsibility for extension: the National Institute of Agriculture (INTA), Argentina, and the National Institute of Agriculture (INIA), Chile. In 2005 INTA created a Center for Research and Technological Development for small-scale family agriculture (CIPAF), with three regional institutes. This signaled a decisive transition from the supply-push Transfer of Technology approach that hitherto characterized the NARI model throughout Latin America, to a client-oriented demand-pull approach based on participatory action-research (http://www.inta.gov.ar/cipaf/cipaf.htm). Since 2003 Brazil has promoted biotechnology as a national policy priority for the Brazilian Agriculture and Livestock Research Company (EMBRAPA) in order to boost productivity in both family farms and large scale agroenterprises. EMBRAPA is collaborating in the federal government's Fome Zero (Zero Hunger) program (http://www.fomezero.gov.br), taking a lead role in the global Cassava

Biotechnology Net (CBN) through the Biotechnology Research Unit of Mandioca e Fruticultura (http://www.cnpmf.embrapa.br) and in Participatory Plant Breeding, principally through EMBRAPA-CNPMF, Cruz das Almas, Bahia, together with the Bahian Company of Agricultural Development (http://www.ebda.ba.gov.br), Caetité, southeast Bahia and farmer communities also located at Caetité.

*The Ministry of Agriculture (MOA) model.* This model was dominant in communist countries and in the immediate postcolonial era and still prevails in countries where this less agricultural research capacity. It is characterized by centralized governance and bureaucratic practice. However, in recent years new organizational patterns have begun to emerge that provide greater flexibility. Collectivization and nationalization resulted in significant and often irrational concentration of agricultural production in state or quasi cooperatives managed as industrial enterprises, affecting the whole social and economic life of villages and rural areas in countries such as Tanzania and in the former soviet bloc countries (Swinnen and Vranken, 2006). Adjustment to new economic and political conditions has demanded significant AKST role changes (Petrick and Weingarten, 2004) including redefinition of the role of government in agricultural research; separation of research funding, priority setting and implementation; decentralization of agricultural research both geographically and in terms of decision making; strengthening of system linkages among multiple innovation partners including CSOs, traders, input and processing industries (Swinnen and Vranken, 2006; Petrick and Weingarten, 2004).

*Universities and other higher education models*. Universities are institutions placed amidst three coordinating forces: the academic oligarchy, the state and the market (Clark, 1983). These three forces are seldom in balance; they act in a continuous and dynamic tension, which often brings about intellectual, practical and organizational conflicts and ruptures (Bourdieu, 1988) often leading to diffuse and contradictory missions (Weick, 1976; Busch et al., 2004). In agricultural universities (schools/colleges or faculties) there are many such divides between purpose and mission; social and scientific power, among managers, teachers, researchers and extensionists; between the established canonical agricultural disciplines and disciplines, such as sociology, ethics and public administration (Readings, 1996; Delanty, 2001). Urgent societal demands, such as those posed by hunger, poverty, inequality, exclusion and solitude, and more recently also natural resource degradation and climate change have had to find their place against the background noises of collaboration and dissent. Universities, nonetheless, are widely identified as key actors in national research systems (Castells, 1993; Clark 1995; Edquist, 1997; Mowery and Sampat, 2004), but their contribution to agricultural research, real or potential, often has been neglected in cost-benefit analyses. Yet they have been and remain the major educators of agricultural scientists, professionals and technicians, a voice of reason (and sometimes partiality) in controversial debates about bioethics, transgenic seeds, IPR, food quality and safety issues, etc., and a source of factual information (Atchoarena and Gasperini, 2002). Robust indicators do not exist for the comparative assessment of the efficiency and effectiveness of universities in generating knowledge, science and technologies for sustainability and development. For example, in a survey of Argentine agricultural scientists (1996 to 1998), the number of journal publications was a proxy measure (Oesterheld et al., 2002), despite known limitations (Biggs, 1990; Gómez and Bordons, 1996; Garfield, 1998; Amin and Mabe, 2000; Bordons and Gómez, 2002). Output was found to be highly variable and on average, low but higher than in other institutions such as the National Institute of Agricultural Technology (INTA), and the National Council for Science and Technology (CONICET) (Oesterheld et al., 2002).

Higher-level agricultural education institutions can be sub-divided into (i) agricultural colleges embedded in a comprehensive university, (ii) land grant universities, patterned after the US land grant universities, and (iii) tertiary level agrotechnological institutes that are not part of a university and depend on a ministry of education or of agriculture. They all have similar constraints to achieving the diversity of their roles and purposes (Table 2-4).

INSERT Table 2-4. Constraints of university arrangements.

(i) *Agricultural schools or college/faculties model embedded in a comprehensive university*. This model is shaped after the German Humboldt tradition and has teaching, research and extension as central functions. It has diffused to other European countries as well as to other parts of the world, mainly the Americas.

Until recently in many countries research universities were autonomous, with public funds provided as block grants by the Treasury to the Ministry of Education, which transferred them to the central university governing body; the agricultural colleges then had to compete against other interests. In Latin American countries, research budgets are often less that 0.5% of the total university budget (Gentili, 2001) and little of this has reached the agricultural departments, colleges and schools. However, in the last decades research has been financed by the use of competitive funds open to all public research institutions and in some cases to private universities. International donors, philanthropic foundations and increasingly also commercial enterprises also contribute to financing (Echeverría et al., 1996; Kampen, 1997; Gill and Carney, 1999). Their main asset is research and their internal system of reward and promotion is designed to protect standards in this core activity. The pressure to 'publish or perish' favors acceptance of actors and types of AKST that is produced in conditions that support such performance and thus tends to increase the gap between developed and developing countries' national academic and research systems. It also further marginalizes scientists and academics in the latter countries where funds for research, in particular for basic research, are scarce. The incentive system legitimated the dominant position of universities in colonial and later in OECD countries as the centers of basic and strategic research in a hierarchy of AKST providers. Students as well as trained agricultural scientists and professionals continue to leave employment in tropical countries wherever national governments have failed to invest in ‘catch up’ institutional development at tertiary levels.

In the United States policies were important in assisting the commercialization of research products and services. The US Bayh-Dole Act passed in 1980 gave universities and corporations the right to patent federally funded research and was buttressed by the Federal Technology Transfer Act of 1986 (Kennedy, 2001; Bok, 2003). These acts succeeded in their primary purpose but widened existing gaps with most developing countries. Incentive systems designed for the commercialization by universities of private good research appear to perform less well in promoting public goods research and its application in agriculture and food industries (Byerlee and Alex, 1998; Berdahl, 2000; Bok, 2003; Washburn, 2005).

The most immediate challenges tertiary institutions face is how to respond to the often divergent interests of private and public actors, consumers and citizens as AKST systems become more demand-driven and hence also develop or strengthen their capacity to become engaged in problem solving in specific settings, and continue to provide generic potential for sustainable development.

(ii) *Land-grant colleges and state universities*. These have been patterned after the land-grant model originating in the 19th century in the United States. Key components are the agricultural experiment station program (Hatch Act 1887) (Kerr, 1987; Mayberry, 1991; Christy and Williamson, 1992; BOA, 1995), and the link via extension programs to farmer advisory, leadership development and training activities in the community. The grant of land to finance research and education ensured in the original conception a high degree of accountability to the application of science to local, practical problem solving and entrepreneurship. These distinctive features tended to attenuate over time or progressively decline as the model spread to and then merged into different contexts. After World War II, the Rockefeller and Ford Foundations and the United States Agency for International Development (USAID) played leading roles in the establishment of state agricultural universities in India modeled on the US land-grant universities. State agricultural universities of Pakistan and the Philippines also adopted the model as their guide. In sub-Saharan Africa, the research and extension missions of the land-grant model generally introduced under Ministries of Higher Education came into conflict with research and extension departments in ministries of agriculture. By the 1980s most of the land-grant universities in SSA had become comprehensive universities emphasizing training. Nevertheless, the model proved powerful; land-grant universities in the USA throughout the 20th century have been central to North America's farm modernization, dominance in commodity trade and pre-eminence in global food industries (Ferleger and Lazonick, 1994; Slaybaugh, 1996; Fitzgerald, 2003). The land-grant construct explicitly rests on concern for both agriculture and rural communities; enterprise development, revenue and welfare; education and research as a privileged knowledge and information activity for faculty and students and as a service to meet citizens' needs. The task of forming, educating and empowering farmers and young farm leaders has been a key strategic objective, resting on tripartite funding contributions from education, agriculture and state agencies at various levels. Farmers have opportunities as well as a right to participate in forming and assessing university research priorities and outputs. Outreach and service count in professional advancement; and the universities' own institutional advancement - even survival – rests on accountability to the broad constituency it serves.

On the other hand, in industrialized countries, particularly in the US, universities have emerged as the nation's main source for the three key ingredients to continued growth and prosperity: highly trained specialists, expert knowledge and scientific advances. There is some evidence that more recent shifts in the balance of public and private funding is affecting the type of research and teaching and hence narrowing the range of available AKST systems. One paradigmatic and controversial case was the agreement between the Novartis Agricultural Discovery Institute and the Department of Plant and Microbial Biology at the University of Berkeley. Under this agreement Novartis provided $5 million per year in support of basic research at the department and in return was given the right to license patents held by the University for up to one-third of the patentable intellectual property developed by the department, with the University retaining the patent rights and earning royalties from the patents. Participating faculty, in turn, received access to proprietary databases held by Novartis (Berdahl, 2000; Busch et al., 2004). The Novartis agreement disquieted those who believed it indicated a transition toward the privatization of public universities; critics argued that by allowing Novartis to participate even as a minority vote on the funding committee, the University was allowing a private company to chart the course of research at the University (Berdahl, 2000). Others pointed out that faculty members applying for research support from the federal government possibly also tailored their applications to increase their chances of support. This situation illustrates the need for codes of conduct in universities to guide their interactions with industry (Washburn, 2005) in order to preserve independence and capacity to deliver disinterested public goods and maintain public trust (Vilella et al., 2002). More public-private partnerships without ensuring such codes may reduce the space for public interest science (Washburn, 2005), although under certain conditions, university partnerships with private actors may contribute to equitable and sustainable development. For instance, the Seed Nursery at the Faculty of Agronomy, Buenos Aires University (www.agro.uba.ar) and the Argentine Agrarian Federation (www.faa.com.ar) developed high-yielding non-Bt corn hybrids (FAUBA 207, 209 and 3760), which are locally adapted and affordable by small-scale farmers and were released to market at less than half the price of the main competitors (Vilella et al., 2003; Federacion Agraria Argentina, 2005; http://www.todoagro.com.ar/todoagro2/nota.asp?id=6542)

*(iii) Agrotechnical institutes*. Postsecondary institutes that are not part of the university system usually depend on public funding from Ministries of Education or Agriculture. They mostly train technicians in agricultural competences related to local labor demand in order to bridge the gap between untrained farmers, semi-skilled technicians and university graduates. However, many developing countries have given little attention to the training demanded by agricultural service agencies and agroindustries. Other countries, such as India or Brazil, invested heavily in such training. In Brazil, the Federal Centers of Technological Education (CEFETs) originated in agrotechnical or technical schools that were upgraded to tertiary-level institutes in the mid-1990s. They have developed good links with the private sector and sometimes share resource training activities through “sandwich courses.” They have become drivers for the application of technology, but an extension worker with certificate-level training and field experience can seldom bridge to a degree program (Atchoarena and Gasperini, 2002; Plencovich and Costantini, 2003). The Sasakawa Africa Fund for Extension Education (SAFE) specifically addresses this need in SSA. Other countries have chosen an alternative agricultural school system shaped after the Maisons Familiale Rurale (rural family house) (Granereau, 1969; Forni et al., 1998; García-Marirrodriga and Puig Calvó, 2007). Today there are more than 1,300 such schools in forty countries, alternating residential training and experience on the family farm. In Argentina, a large group of secondary public schools managed privately by NGOs, foundations, and other private actors and federated under the umbrella of an apex organization (FEDIAP; http://www.fediap.com.ar/) manages 3,000 teachers and about 15,000 students, taking occupational education deep into marginal and vulnerable areas (Plencovich and Costantini, 2006).

### *2.2.3 Producers of AKST at regional and international levels*

The institutional arrangements for development-oriented AKST at international levels have evolved from rather simple relationships organized largely by and in support of colonial interests, through focused support organized through the CGIAR system largely under the guidance of multilateral and bilateral development organizations, to arrangements that are rapidly diversifying under market pressures. The increasing attention to environmental issues, especially from the early 1980s onwards, also gave rise to arrangements that made effective use of collective capacity to address shared practical and policy problems related to such issues as watershed management, vector-borne diseases and biodiversity conservation efforts. Examples include CSOs, such as the South East Asian Regional Initiatives for Community Empowerment (SEARICE) in the Philippines (cf. http://www.searice.org.ph/), which serves as the secretariat for region-wide advocacy, lobbying and action among networks of CSOs to promote and protect farmers' seed exchanges and sales and to ensure legal recognition of farmer-bred varieties and of community registries of local plants, animals, birds, trees, and microorganisms. SEARICE has become a major actor in the establishment of community-based native seeds research centers, such as CONSERVE in the Philippines and Farmer Field Schools for plant genetic resource conservation development and use in Laos, Bhutan, Vietnam and community biodiversity conservation efforts in Vietnam, Thailand, and the Philippines. SEARICE today is recognized as an effective and legitimate partner in sustainable and equitable development. The Mekong River Commission (MRC) offers a different kind of arrangement; founded in 1995 by the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin (http://www.mrcmekong.org/). It is funded by contributions from the downstream member countries (Cambodia, Laos, Thailand, Vietnam) and donors and is considered an important institutional innovation that is successfully bringing together cross-sectoral knowledge and helping actors to learn from policy experiments. However economic drivers within the member states resulting in upstream development of irrigation and hydroelectric power in China are undermining local efforts to forge more sustainable development pathways (Jensen, 2000; MRC, 2007). In SSA regional AKST arrangements have emerged and today their NARIs also act as regional service centers. ASARECA and CORAF were established in the late 1990s in eastern and western Africa respectively to fill gaps and build on strengths but no assessment can yet be made of their effectiveness. In southern Africa the formalization of inter-state collaboration in AKST has not yet occurred. The South African Agricultural Research Council and universities continue to provide a regional back up service and various R&D networks seek to fill some of the severe gaps in public and private capacity.

The tropical AKST institutions established by the colonial powers, such as the Royal Tropical Institute (Netherlands) or the Institut de Recherche pour le Développement (formerly ORSTOM) (France) and their supporting university networks similarly have surrendered their dominance and undergone major transformations over the period (Jiggins and Poulter, 2007), yet they remain collectively the largest source of knowledge on the diversity of ecological and ethnic situations in the tropics. These institutional arrangements were generally effective for their initial purpose, but they badly neglected the food crops consumed by indigenous populations, with the exception of a few such as the federal research station for French West Africa created in 1935 to increase food production (Benoît-Cattin, 1991). The International Agricultural Research Centers (IARCs), subsequently grouped under the CGIAR umbrella, was in part a response to this gap.

*CGIAR.* Assessing the role of the CGIAR is fraught with difficulties, mainly because of the controversies raised by this important actor, since its inception. Several external reviews of the CGIAR took place in the 1990s (World Bank, 2003), most of them organized by the CGIAR itself, indicating a willingness to change and adapt but also some uneasiness about the way the CGIAR worked, chose its priorities and was governed. However, the reviews did not fully address some of the more fundamental questions raised by the critics. There is insufficient space here to do justice to all these debates.

*Creation of the CGIAR*. The role of the two US-based foundations, Rockefeller and Ford, in the creation of the first international centers has been well-documented (Baum, 1986). The first international research center, the International Maize and Wheat Improvement Center – in Spanish, CIMMYT- was devoted to wheat and maize, the second one – the International Rice Research Institute (IRRI) established in the Philippines in 1960- to rice. This early emphasis on cereals, i.e. on staple food crops, was a direct reaction, befitting the philanthropic nature of the two foundations, to the emphasis on plantation crops during the colonial era.

The emergence of this new type of institutional configuration had a profound impact on the IAs for agricultural research in developing countries. In this respect, the rapid evolution of the role of IRRI is exemplary. The first high-yielding (HY) rice cultivar released by IRRI (IR8) grew out of a dwarf gene which originated in Japan. Soon, however, its limitations became obvious. The new variety was sensitive to multiple pests and did not have the taste desired by many in Asia. The second generation of HY cultivars released by IRRI grew out of elaborate collaborations among many national research institutions in Asia, permitting a quantum jump in the exchange of genetic material and the coordinated testing of new genetic material in multiple locations. These new kinds of IA's, based on networking among public research institutions, with the hub located at an international center, set a pattern for the future. The role of the international centers in the development of new and more productive staple crop varieties has been well documented (Dalrymple, 1986) and is not by itself a controversial issue.

*Early criticisms.* But early on, extensive criticisms were expressed; in particular, it was pointed out that a technological change, however rapid and even if called a revolution as in the expression 'green revolution,' could fall short of the radical changes in agrarian structures which many felt were necessary to tackle the most glaring inequalities associated with unequal access to productive resources, land in particular (Griffin, 1979; Griffin and Khan, 1998). One must recall in this respect that the Green Revolution (GR) came after many attempts at promoting land reforms or agrarian reforms. Many of the reform attempts were made in a climate of bitter social struggles, often violent. In this context, the promotion of an international consensus in support of a technology-led green revolution could be seen as an alignment with conservative forces, nationally and internationally (Frankel, 1971). A similar criticism saw the GR, the CGIAR and their promoters such as the World Bank, which indeed had played a crucial role in the formal creation of the CGIAR, patterned on other consultative groups sponsored by the Bank, as an attempt at 'liquidating peasantries' in developing countries (Feder, 1976). These criticisms prompted a large body of empirical research and interpretative analyses to evaluate the impact of the GR on poverty and the survival of small-scale producers. The assessment of the merits and limitations of the transfer of technology (ToT) model draws on that literature (2.1) (Harris, 1977; Lipton and Longhurst, 1989; Biggs and Farrington, 1991; Hazell and Ramaswamy, 1991; Lipton, 2005). One important lesson was that the social impacts of the technological changes associated with the GR varied greatly in space and in time. This should not come as a surprise since we know that technological change is only one component in the complex evolution of social realities yet the implications for how AKST were conducted within the CGIAR and with the CG's partners did not immediately sink in. The controversies themselves also reflect the fact that many views expressed in the controversies were oversimplifications drawn from limited empirical data, giving privileged attention to some aspects of the complex phenomena involved.

Similarly, the debates on the role of the CGIAR in the impact of the GR on the environment have been heated (2.1). Those who defend the GR and the CGIAR emphasize the millions of hectares of primary forests and other lands saved from destruction through the intensification of existing cropland that the GR permitted (see Borlaug's numerous public speeches on the topic). There is no doubt, however, that negative environmental effects, ranging from pollution to degradation of land and water resources also have been significant (Byerlee, 1992). Another environmental consequence, the increase in the uniformity of crop germplasm, with all the risks that the corresponding loss of biodiversity entails, roused similar controversies (Hogg, 2000; Falcon and Fowler, 2002).

*Subsequent evolution of the CGIAR.* These debates and the recognition that many issues were not well addressed led to changes within the CGIAR. For instance, it was recognized that the focus on individual crops had serious limitations. Mixed farming – the basis of many small-scale farming systems-, agroecosystem sustainability and the management of natural resources had not been addressed systematically. The two livestock-focused centers had not achieved impacts comparable to the crop-focused centers. These concerns led to the creation in the 1970s and 1980s of a further wave of international agricultural research centers that were initially outside the ambit of the CGIAR (e.g. IWMI: water and irrigation, IBSRAM: soils, ICRAF: agroforestry, ICLARM: aquatic resources, and INIBAP: plantains and bananas). Generally speaking, the newer institutions developed more extensive networks of partnerships with a wider range of civil society and public agencies than the original crop research centers. In the early 1990s, some of the new centers were brought into the CGIAR ambit, after much discussion and resistance by those who feared that the expansion of the CGIAR would entail a reduction in funding for the original centers. Two major concerns drove this expansion: the perceived need to widen the research agenda to include a systematic focus on natural resource management, and a broad recognition of the need for CGIAR centers to diversify their partnerships and networking capacity. The international centers were thus driven by a growing pressure to address new issues, mainly related to natural resource management, and to address more directly than before the needs of the poorest producers and of under-valued clients, such as women (Jiggins, 1986; Gurung and Menter, 2004).

In response to donor calls for more efficient, collaborative and cost-effective approaches, the CG centers opened up to new modes of collaboration, including ‘system-wide programs’ that draw together expertise from across the range of centers and other AKST actors in order to focus on specific themes and the development of ‘partnerships for innovation’. The increasing focus on innovation in turn required the centers to pay more attention to institutional issues and the contexts in which a technology is inserted and to seek a wider range of partners in recognition of the emerging global architecture for AKST (Petit et al., 1996). However, the rate of change within the CG was considered by its funders to be too slow and indecisive. One of the solutions was the introduction of well-resourced, multistakeholder, regionally focused “Challenge Programs” (CGIAR, 2001), often including a competitive research grant component. Their emphasis on multiple partnerships is a potentially significant institutional development for the CGIAR system. As yet however, there is insufficient evidence to assess their contribution to sustainable development or to driving change within the CG. The Global Forum on Agricultural Research (GFAR) was established in 1996 as a complementary initiative to promote global leadership in AKST for shared public interest goals; currently there is insufficient data for an assessment of GFAR’s effectiveness.

*Current debates*. In spite of the changes briefly sketched above, the debates and controversies about the CGIAR have not disappeared. For some, “the CGIAR and the GR that it created have arguably been the most successful investments in development ever made” (Falcon and Naylor, 2005). Yet criticisms abound. The old fundamental questions regarding the insufficient inclusion of the poor and marginalized and the consequences on the environment, particularly the loss of biodiversity, have not been resolved in the eyes of many. Another criticism, often heard but seldom formalized, is that the CGIAR is very much part of the 'establishment' and not sufficiently receptive enough to new ideas. An illustration of this resistance to change is the assessment by social scientists (other than economists) that their expertise has not been used as effectively as possible (a few have now been integrated into some CG centers) (Rhoades, 2006; Cernea and Kassam, 2006). Another frequent criticism, often heard in donor circles but not often openly expressed, is that many centers are not open enough to broad partnerships with multiple and diverse actors. Others continue to fear a dilution of the main mission and unique role of the CGIAR, lest it drift more and more towards becoming a broad based development agency. Thus, some convincingly argue for a stronger CGIAR focus on international public goods through its attention higher productivity, particularly for orphan crops (Falcon and Naylor, 2005). One lesson to draw from this debate may be the relevance of, but also the difficulties associated with, the use of the concept of global public goods (Dalrymple, 2006; Unnevehr, 2004).

*Food and Agriculture Organization of United Nations (FAO)* was founded in October 1945 under the United Nations as a key pillar of the post WWII reconstruction, with a mandate to raise levels of nutrition and standards of living, to improve agricultural productivity and the condition of rural populations. From 1994 onwards, it has undergone significant restructuring in an effort to increase the voice of tropical countries in its governance and priority setting and in response to advances within AKST and the changing architecture of public and private provision. Although remaining heavily male-dominated in its staffing and leadership, it has been a significant global actor in creating awareness of gender issues, stimulating growth with equity and in linking nutrition, food security and health issues.

It has played a leading role in organizing disinterested technical advice in the international response to the health and environmental concerns associated with synthetic chemical pesticides (see 2.3.2), leading among other important outcomes to the International Code of Conduct on the Distribution and Use of Pesticides and efforts to remove stockpiles of obsolete pesticides. This code has encouraged many countries to adopt pesticide legislation and regulations although governments may experience difficulty in implementing and managing pesticide regulations in the face of competing interests (Dinham, 1995). The FAO similarly has played a critical role also in international efforts to protect crop genetic diversity through the International Treaty on Plant Genetic Resources for Food and Agriculture. One of the important spin-offs so far is the Global Crop Diversity Trust hosted jointly by FAO and IPGRI (http://www.fao.org/ag/cgrfa/itpgr.htm).

*The World Bank*. The World Bank Group was established as another of the key pillars of post World War II reconstruction. It consists of the International Bank of Rural Development (IBRD), the International Development Agency (IDA), International Finance Corporation (IFC) and

Multilateral Investment Agency (MIGA). The Group has been and remains a leading global player in development policy, funding and advisory efforts. It has invested heavily in economic and service infrastructures in rural areas; it was an early backer and consistent supporter of the emerging CG system and particularly through the 1980s dominated investments in agricultural extension and advisory systems in developing countries. The World Bank directly shapes the development path of many borrower countries through its research and through structural adjustment programs that restructure national economies or specific sectors (including agriculture). Yet Bank agricultural lending has decreased steadily over the past 60 years; currently it constitutes less than 10% of IBRD and IDA lending. The very mixed effects of these trends and shifts in financing on AKST and on innovation in the agricultural sector have been assessed in the 2008 World Development Report on Agriculture (World Bank, 2008). Internal as well as external analysts over the last 15 years have recommended that the trend be reversed.

Like other development actors, the World Bank has evolved over the decades in response to different drivers, external pressures and internal experiences (Stone and Wright, 2007). According to one narrative, the Bank initially perceived its central role as the transfer of capital from rich countries to poor ones. The bulk of its portfolio lay in infrastructure projects developed by engineers. In the 1970s, Bank management concluded that infrastructure development alone was not sufficient to eliminate poverty and so Bank agricultural economists focused on “poverty alleviation.” In the 1980s, macroeconomists, who played a leading role in designing investment projects at the Bank, viewed the debt crisis as evidence that sectoral development efforts could not succeed in the presence of major macroeconomic imbalances. Powerful interests in industrialized countries (where commercial banks feared that the loans they had made to developing country governments were at risk), pressured their government representatives in the Bank, and in the IMF to intervene. Accordingly, Bank management promoted structural adjustment programs as a condition of its lending. In the 1990s, the Asian economic crisis demonstrated that a narrow macroeconomic perspective was not appropriate for the pursuit of a sustainable development agenda, and the role of social sciences was gradually recognized. Changes in the hierarchy of professional disciplines within the Bank did not come about smoothly. Struggles eventually led to greater inclusion of the social sciences (Kardan, 1993); Ismail Serageldin, a Bank vice-president, spelled out why non-economic social scientists were not listened to earlier and delineated key intellectual challenges that remained to be faced (Cernea, 1994).

Political economic, anthropological and ethnographic analyses have also assessed the role of the Bank (Wade, 1996, 1997, 2001, 2004; Ferguson, 1990; Harris, 2001; Mosse, 2004a; Broad, 2006; Bebbington et al., 2007). Simple causal linkages between external event, internal analysis, policy formation and subsequent implementation have been questioned (Mosse, 2004b). Evidence suggests that the Bank through its principal research unit has constructed, defended, maintained and promoted a neoliberal paradigm, despite changing contexts and emerging empirical evidence that challenge this paradigm (Broad, 2006). Organizational dynamics and international political economy have consistently shaped policy statements produced by the Bank over the period, while organizational culture—the everyday imperative to disburse loans and move projects through the pipeline, the internal incentive structure, hiring, staffing and subcontracting decisions and, importantly, power relationships within the Bank and between it and other actors—have been more decisive determinants of the outcomes of Bank interventions than its policy statements (Liebenthal, 2002; Mosse, 2004a; Bebbington et al., 2007). The empirical evidence indicates a need for more political economy and social science-based analyses of the World Bank's institutional behavior, culture, internal and external power relations and dynamics, and outcomes in terms of equitable and sustainable development.

The positive role of the Bank in the provision of financial resources to AKST includes loans to many governments in support of public agricultural research and extension institutions. Such support usually accompanied commitment to institutional reforms of these institutions. For instance, in Mali a Bank loan permitted the creation of research user committees at the level of regional research centers. These committees were designed to give a voice to farmers in the selection of research topics and in the evaluation of the usefulness to them of research results. The initiative gave some space for educated farmers with more resources to participate in research agenda-setting. In India, a large loan made in the late 1990s promoted significant reforms in the large Indian public sector agricultural research establishment, which had become quite bureaucratized. In Brazil, the volume of the loan made in the late 1990s was relatively modest; it was used by the then new leaders of EMBRAPA, the national research institute, to facilitate institutional reforms. The impact of Bank supported projects have been assessed and documented by the Bank's own Operation Evaluation Department (OED), a quasi-independent body which, while providing a degree of critical analysis, admittedly often reflects the dominant ideology in the Bank. Accordingly, the final and critical evaluation by OED of the T&V agricultural extension system, long promoted by the Bank particularly in Africa, was published only in 2003 (Anderson, Feder, and Ganguly, 2006) i.e. long after the shortcomings of T&V had been emphasized by its critics; thus internal institutional learning and reform has been slow.

1n 1992, the Bank joined 178 governments in committing itself to Agenda 21, a global effort to articulate the link between environment and development issues. An internal World Bank review of progress towards environmentally sustainable development found that it had failed to integrate environmental sustainability into its core objectives or to forge effective cross-sectoral linkages between environmental and other development goals (Liebenthal, 2002). External assessments similarly found that the Bank had not lived up to the expectations of its Agenda 21 commitment (FOE/Halifax Initiative, 2002). A four-year Structural Adjustment Participatory Review Initiative, in which the World Bank participated, reported that the effects of the Bank's structural adjustment programs on the rural poor over the past 20 years had been largely negative (SAPRIN, 2002). External analyses likewise found that these programs tended to drive the evolution of AKST towards high external input models of production, while the pressure of debt repayment schedules in turn prevented governments from investing in poverty-oriented multi-sector sustainable development programs at home (Hammond and McGowan, 1992; Danaher, 1994; Korten, 1995; Oxfam America, 1995; Clapp, 1997; McGowan, 1997; Hellinger, 1999; SAPRIN, 2002).

An important lesson is that both because of its size and its role as a financial institution, the World Bank has not been deft in its interventions in countries' institutional arrangements, particularly at the local level. This is a damaging limitation because as other subchapters demonstrate, appropriate institutional arrangements, particularly at the local level, are critical to the effectiveness of AKST in terms of the Assessment's criteria of equitable and sustainable development. The Bank also has faced numerous demands in the area of AKST from other development funding agencies that are willing to fund initiatives through "trust fund arrangements." The danger that the Bank could be drifting too far from its primary role as a financial institution has been keenly felt by some senior managers; as a result, the Bank has at times taken up and then dropped AKST initiatives that may have been worthwhile in advancing broader development goals. The consequences of its brief attention to these issues have not been well assessed. The other regional development banks have not held the central and symbolic role of the World Bank. But they also have played an important role in their region and have sent powerful signals regarding their AKST priorities to client governments. More in-depth social scientific analyses of the nature of the banks' interactions with other AKST actors and their contributions to equitable and sustainable development, is warranted.

### *2.2.4 Public-private and private sectoral arrangements*

*Public-private arrangements*. A number of countries have relied on multi-organizational partnerships to carry AKST to small-scale producers. For instance, the Foundation for the Participatory and Sustainable Development of the Small-scale producers of Colombia (Spanish acronym, PBA) brings together members of the Ministry of Agriculture and Rural Development, the Ministry of the Environment and the DNP (National Planning Department); international research centers, such as CIAT (International Center for Tropical Agriculture); research agencies such as CORPOICA (Colombian Corporation of Agricultural Research) and CONIF (National

Agency for Forestry Research); national and regional universities and local farmers' organizations. It is responsible for bringing together at local levels the expertise and support required for small-scale producers and rural entrepreneurs in research, technology generation, and extension and agroenterprise development. The Andean consortium, established in the early 1990s on the initiative of the PBA, brings together five Andean countries (Venezuela, Colombia, Ecuador, Peru and Bolivia) under a regional project in order to strengthen participative exchange of research and technology with small-scale producers, as well as mobilize international cooperation in AKST and funding. The project has significantly advanced understanding of the small farm economy, established a strong nucleus of expertise in participatory research, developed the scientific, adaptive and applied research infrastructure and established key agroenterprises for the production of clean seed and bio-inputs, and initiated links with private commercial actors in the development of value-adding chains in export-oriented markets, e.g., cut flowers, tropical fruits and counter-season vegetable supply.

Organizations such as *Solidaridad* have extended the concept and practices of public-private partnerships by linking fair trade to high return markets, such as the fashion industry and more recently, by moving an increasing amount of fair trade product into mass marketing. This effort is being guided by the multistakeholder negotiation of Codes of Conduct. For instance, the Common Code for the Coffee Industry was introduced in September 2004. It is currently operating in Vietnam and Uganda, with major expansion from 2006 onwards under the sponsorship of the German Ministry for Development Cooperation, the German Coffee Association, producer associations and major coffee processors, such as Nestlé, Tchibo, Kraft and Sara Lee, and international organizations such as Consumers International.

*Private sector arrangements for profit.* The last sixty years have witnessed a rapid increase in the concentration of commercial control by a handful of companies over the sale of planting seed for the world's major traded crops – by 1999, seven companies controlled a high percentage of global seed sales and the concentration has since increased through take-overs and company mergers. The budgets of the leading six agrochemical companies in 2001-2002 combined equaled US$ 3.2 billion – compared to a total CGIAR budget in 2003 of US$ 330 million, an order of magnitude less (Dinham, 2005). At the same time, national small and medium-sized seed companies have emerged, playing an important role for small-scale producers and niche markets. They may result in improved market access by small-scale farmers to locally adapted and affordable seed but this remains to be proven. Interesting innovations include the following three examples. The Seeds of Development Program (SODP) is a capacity development and network initiative that seeks to alleviate rural poverty through improved access to appropriate seed varieties. It offers an innovative program for small and medium sized indigenous seed companies in Africa. The network currently includes 25 seed companies in eight African countries. The SODP has been developed by Market Matters, Inc., a US-based organization working in collaboration with Cornell University. Private seed companies operating in India for many years relied on ICRISAT-bred hybrid parents and while gradually developing their own research and development capabilities; over time they became a major channel for large-scale farm level adoption of hybrids derived from ICRISAT-bred hybrid parents or their derivatives. ICRISAT realized that such partners have better integrated perceptions of farmers' preferences and this triggered the initiation in 2000 of the ICRISAT-Private Sector Hybrid Parent Research Consortia for sorghum and pearl millet. The consortia expanded to include pigeon pea in 2004. Small and medium sized manufactures of agricultural machinery and equipment, specialized for conservation agricultural equipment (e.g. no-till seeders and planters), especially in Brazil, provide agronomic assistance to farmers and advice on conservation agriculture, which simultaneously increases their own market.

#### *2.2.5 NGOs and other civil society networks*

Nongovernmental organizations (NGOs) are the so-called 'third sector' of development, which is different from but interacts with both the state (public) and the for-profit private sector in AKST relationships ranging from complementarily to challenge (Farrington and Lewis, 1993; Farrington et al., 1993). The NGO sector developed in response to the actual and perceived failures or shortcomings of the state, a desire to examine developmental questions from motives other than those of profit and to question and analyze interests, priorities and the conditionalities imposed by donor agencies and other organizational actors. A fundamental basis of NGO activity is voluntarism (Uphoff, 1993) and this conditions NGO perspectives and scope of action and imposes a degree of similarity on what is an otherwise diverse domain. The diversity in the domain may be usefully classified by the origin of the NGO (Southern, Northern, Northern with activities in the South etc.); the nature of the work - grassroots organizations (such as communities, cooperatives, neighborhood communities, etc.), organizations that give support to the grassroots, and those that (whether in addition to other activities or solely focused on this) are engaged in networking and lobbying activities; their funding; relationships with the state and private sector; their membership base; their size, staffing and relationships with their constituencies (which could be as diverse as rural farmers, urban slum dwellers, indigenous tribes), and the mechanisms and procedures in place for accountability (Farrington and Lewis, 1993; Farrington et al., 1993). In the case of the agricultural sector, the main types of NGOs encountered are those working directly with farmers with close involvement in dissemination of farming techniques and processes, provision of agricultural inputs, technologies, access to markets and implements (i.e. developmental NGOs); NGOs that are engaged in conducting research on agricultural crops, processes and products (research NGOs); NGOs that lobby for specific issues related to agriculture ranging from farm-worker health, to gender empowerment among farming communities, to advocating for specific regional, national and international agriculture and trade policies (advocacy NGOs); NGOs focusing on activities such as microcredit for farmers and agricultural communities (support NGOs).

The nature of activities that NGOs undertake, their relationship with the state and the private sector, their core constituency and nature of their involvement with it, their own organizational character and staff profile determine the attitude of an NGO towards the kinds of knowledge it considers valid and consequently the nature of knowledge processes it engages with and utilizes in its interactions with its constituency (Pretty, 1994). The processes of engagement range from the commissioning of research providers to inform NGO action, top-down dissemination of knowledge through NGO community trainers to engagement with farming communities in research and enquiry through user groups and participatory committees and direct involvement of farming communities in research agenda setting and knowledge selection. NGOs have become significant players in AKST. One of the largest member-based NGOs, BirdLife International has become a significant player in organizing civil society-based collection of data that informs local, national and global environmental policy and conservation effort. Local groups affiliated to this NGO and to WWF (World Wildlife Fund) were instrumental in ensuring that attention was paid to the impacts on native biodiversity in UK trials of GM oil seed rape and other selected field crops. Collaboration among three Indian NGOs (Deccan Development Society, Andhra Pradesh Coalition in Defence of Diversity and Permaculture Association of India) supported the first thorough assessment of Bt Cotton from farmers’ perspectives (Qayum and Sakkhari, 2005).

## 2.3 AKST Evolutions over Time: Thematic Narratives

The implementation and evolution of different IAs (sub-chapter 2.2), have been causes as well as consequences of the main changes in AKST. Although it now appears that AKST presents itself as a whole, or at least as a tightly intertwined ensemble of domains, it has not always been the case. Progressively, over centuries, a hierarchy has developed between scientific knowledge, technological knowledge and agricultural production, the latter being progressively limited to the execution of external recipes. Paralleling this hierarchy, science itself established a hierarchy between emerging and evolving disciplines: chemistry, biology, genetics, botany, entomology, economy, sociology, and anthropology are permanently struggling for recognition, status and resources, and scientists engage in alliances with other actors in this purpose. Science allied with technology branched out in different domains of application that resulted in new professions related to various aspects of agricultural production, its products and impacts. Hence, in modern times is that the role of scientific research in maximizing agricultural productivity has increased exponentially (Cernea and Kassam, 2006). However, through the last decades, a reverse movement has occurred and the division between the different branches of AKST have been blurred, the great divide of labor between science and technology is currently challenged, the hierarchy among disciplines reveals its shortcomings and the role of public and private actors has changed.

The following narratives are illustrative of how AKST contributed and shaped (as well as resulted from) the management of three major elements: seeds, pests, and food. These narratives identify trends, turns, and bifurcations in each domain and look at the major actors who managed them, in response to drivers relevant for them.

### *2.3.1. Historical trends in germplasm management and their implications for the future*

#### 2.3.1.1. Summary of major trends in the history of global germplasm management

Genetic resource management over the past 150 years has been marked by an institutional narrowing with the number and diversity of actors engaged in germplasm management declining. Breeding has largely become an isolated activity, increasingly separated from agricultural and cultural systems from which it evolved (Box 2-1).

This narrowing is illustrated in history by four major trends: (i) a movement from public to private ownership of germplasm; (ii) unprecedented concentration of agrochemical, seed corporations, and commodity traders; (iii) tensions between civil society, seed corporations, breeders and farmers in the drafting of IPR; (iv) stagnation in funding for common goods germplasm. These trends have reduced options for using germplasm to respond to the uncertainties of the future. They have also increased asymmetries in access to germplasm and benefit sharing and increases vulnerabilities of the poor.

INSERT Box 2-1. Timeline of genetic resource management.

For example, farmers have received no direct compensation for formerly held public accessions that have been sold on to the private sector but have generally benefited from public breeding arrangements. It remains a question if farmers now have to pay for accessing seed stock and germplasm that contain lines and traits that originally were bred by them and originated in their own farming systems. Meanwhile, decreases in funding for public breeding has stagnated research innovations for the public good (e.g. lack of research on orphan crops). New ownership and IPR regimes have restricted movement and made development of noncommercial (public) good constructs more expensive. These changes have limited those actors that do not have legal, commercial and financial power.

### 2.3.1.2. Genetic resources as a common heritage

*Farmers as managers of genetic resources.* Historically, farmers have been the principal generators and stewards of crop genetic resources (e.g. Simmonds, 1979). This means that genetic resources have been viewed as a common heritage to be shared and exchanged. The concept places farmers at the center of control of their own food security. The planting of genetically diverse, geographically localized landraces by farmers can be conceptualized as a decentralized management regime with significant biological (Brush, 1991; Tripp, 1997; Almekinders and Louwaars, 1999) and political (e.g. Ellen et al., 2000; Stone, 2007) implications. Studies of traditional farming systems suggest that farmers in Africa (Mulatu and Zelleke, 2002; van Leur and Gebre, 2003) the Americas (Quiros et al., 1992; Bellon et al., 1997, 2003; Perales et al., 2003) and Asia (Trinh et al., 2003; Jaradat et al., 2004;) managed and continue to manage existing varieties and innovate new ones through a variety of techniques including hybridization with wild species, regulation of cross-pollination, and directional selection (Bellon et al., 1997). In many parts of the world, it is women’s knowledge systems that select and shape crop genetic resources (Tsegaye, 1997; Howard, 2003; Mkumbira et al., 2003). The fear is that erosion of crop diversity is commonly paralleled by erosion of the farmer’s skills and farmer empowerment (Bellon et al., 1997; Brown, 2000; Mkumbira et al., 2003; Gepts, 2004). This loss of farmer’s skills (i.e., agricultural deskilling; see Stone, 2007) means a loss of community sovereignty as less of the population is able to cultivate and control their own food (see 2.3.3).

*Development of public and private sector.* The public sector emerged to catalyze formal crop improvement, focusing on yield with high input requirements and wide adaptability (Tripp 1997; Almekinders and Louwaars, 1999). Major benefits arose from breeding with large, diverse germplasm populations. These advancements had both negative and positive impacts on farming communities as more uniform crops replaced locally adapted crops. Meanwhile, expeditions to collect global germplasm were underway by several nations and gene banks were established for the conservation of germplasm for use in research and breeding.

Public sector institutions were the dominant distributors of improved varieties in first half of the 20th century, aiming to reach as large a constituency possible. Where different forms of mass selection formed the main breeding method in the 19th century, the rediscovery of Mendel’s laws of heredity (1900) and the discovery of heterosis (1908) spurred the growth of the commercial industry, most notably with the founding of Pioneer Hi-Bred in 1919 (Crow, 1998; Reeves and Cassaday, 2002). Throughout the 20th century, universities and research institutes gradually specialized in basic research while the private sector increased its capacity in practical breeding. The public sector assumed primary responsibility for pre-breeding, managing genetic resources and creating scientific networks that acted as conduits of information and technology flow (Pingali and Traxler, 2002), and creating regulatory bodies for variety testing, official release, and seed certification.

*The first institutional arrangements exported to developing countries.* The education, research and extension system triangle commonly found in industrial countries was exported to developing countries to help foster agricultural development and food security, mainly through the development of broadly adapted germplasm. With the aid of the Rockefeller Foundation (and later the Ford Foundation), a collaborative research program on maize, wheat and beans in Mexico was founded in 1943. This laid the foundation for the first international research centers of the CGIAR, with the initial focus to improve globally important staple crops (see 2.2.4).

The formation of the CGIAR centers laid the groundwork for the emergence of the technologies of the Green Revolution. Borrowing from breeding work in developed countries, high yielding varieties (HYV) of rice, wheat, and maize were developed in 1960s and 70s. By the year 2000, 8000 modern varieties had been released by more than 400 public breeding programs in over 100 countries. The FAO launched a significant program to establish formal seed production capacities and so-called ‘lateral spread’ systems in developing countries to make the new varieties available to as many farmers as possible. These public seed projects, financed by UNDP, World Bank and bilateral donors were subsequently commercialized, often as parastatal companies, before national or multinational seed companies were established in these developing countries (World Bank, 1995; Morris 1998; Morris and Ekesingh, 2001).

The FAO has estimated the economic and social consequences of crop genetic improvement gains emanating from the international agricultural research centers using the IFPRI based model ‘IMPACT’ (Evenson and Gollin, 2003b). Without CGIAR input, it is estimated that world food and feed grain prices would have been 18-20% higher: world food production 4-5% lower, and imports of food in developing countries about 5% higher. Debates continue as to whether increases in food production, such as those of the Green Revolution, necessarily lead to increases in food security (IFPRI, 2002; Box 2-2; see 2.3.3).

INSERT Box 2-2. Historical limitations of CGIAR arrangements.

*Sharing of genetic resources as historical norm.* Until the 1970’s, there were very few national and international laws creating proprietary rights or other forms of explicit restriction to access to plant genetic resources. The common heritage concept of genetic resources as belonging to the public domain had been the foundation of farming communities for millennia where seed was exchanged and invention was collective (Brush, 2003). Farmers and professional breeding have relied on genetic resources, in the public domain or in the market, to be freely available for use in research and breeding. The public-sector research ‘culture’ is based on this tradition of open-sharing of resources and research findings (Gepts, 2004) although this is changing (see below), with serious social and political implications. Indeed, the global collaboration required for the development of the HYVs of the Green Revolution demonstrated the effectiveness of an international approach to sharing of germplasm. The International Undertaking on Plant Genetic Resources, 1983, encapsulated this spirit citing the “universally accepted principle that plant genetic resources are a heritage of mankind and consequently should be available without restriction.” Since that time, in many ways, the common heritage principle has been turned on its head, with the gradual encroachment of claims for control over access to and use of genetic resources grounded in IP laws, assertions of national sovereignty (Safrin, 2004) and or the intentional use of technologies that cannot be re-used by farmers.

The common heritage or public goods approach to the use of Plant Genetic Resources for Food and Agriculture (PGRFA) has not been entirely eclipsed. It is worth noting in this regard that the Union for the Protection of Plant Varieties (UPOV) Conventions through their several revisions to further strengthen breeders’ rights have consistently maintained a “breeders’ exemption” which allows researchers/breeders to use protected materials in the development of new varieties without the permission of the owners (as long as the new varieties are not ‘essentially derived’ from the protected varieties). Furthermore, in what might be considered a surprise development in the context of the overall shift in the genetic rights paradigm, the International Treaty on PGRFA creates an international research and breeding commons within which individuals and organizations in member states, and international organizations that sign special agreements, enjoy facilitated access (and benefit sharing) on preset, minimal transaction costs. Farmers and other target groups of this assessment have been inadvertently, and largely negatively, affected by the battles over genetic rights.

### 2.3.1.3. Major change in germplasm management

*The development of IPR in breeding.* The business environment and size of the market are important factors for investment. Intellectual property rights (IPR) provides a level of protection. With the introduction of IPR, the private seed industry has benefited from the ability to appropriate profits to recoup investments and foster further research, organizational capability and growth (Heisey et al., 2001). The stakes are high; IPR regimes have transformed the US $21 billion dollar global seed market and contribute to the restructuring of the seed industry (ETC, 2005).

The increasingly international character of IPR regimes is a reflection of widespread and integrated trade in germplasm resources as well as global trends toward liberalization of markets and trade, privatization, and structural adjustment that reduce the role of the public sector (Tripp and Byerlee, 2000).

*An evolution towards stronger IPR protection.* Germplasm protections have been both biological; (e.g. hybrid maize) and legal. Initially plants were excluded from patentability for moral, technical and political reasons. For example, special, so-called *sui generis* protection was developed for asexually reproduced plants (US Plant Act 1930). In Europe protection for all varieties in the 1940s was harmonized through the Union for the Protection of Plant Varieties (UPOV) (1961). This Plant Variety Protection (PVP) system recognized farmers and breeders exemptions. While PVP offers protection to private seed producers by prohibiting others from producing and selling the protected variety commercially, it does not restrict anyone from using a protected variety as parental material in future breeding. This is known as ‘farmer’s privilege’ and responds to the traditional seed handling mechanisms which allows farmers to save and exchange seed (1978 Act), a provision which was interpreted very widely in the USA, leading to large scale ‘brown bagging.’

Utility Patents (UP) on a bacterium in 1980 signaled the advent of an era of strong IPR (Falcon and Fowler, 2002), marking the end of ‘farmer’s privilege,’ which was restricted in the latest revision in UPOV (1991 Act). This loss of privilege generated heated debate among ratifying countries, especially developing nations, because it limits the rights of farmers to freely save, exchange, reuse and sell agricultural seeds (Tansey and Rajotte, 2008).

Patents entered plant breeding initially through court decisions in the USA in the 1980s via association with biotechnology. They were subsequently granted in other OECD countries, and offered greater protection to a wider array of products and processes, such as genes, traits, molecular constructs, and enabling technologies (Lesser and Mutschler, 2002). However, varieties are excluded from patentability in most countries. The EU introduced a breeder’s exemption into its patent law, and some EU countries have introduced a farmer’s privilege to avoid the pitfalls of excessively strong protection (World Bank, 2006).

*IPR limitations.* Even though IPR may be important for private seed sector development, some sectors have been successful in developing countries without IP protection. For example, the private seed sector in India has grown and diversified without the benefit of IPRs but in the context of liberal seed laws and in many cases through the use of hybrids as a means of appropriation (Louwaars et al., 2005).

Some indicators suggest that the IPR in developing countries may have occurred primarily as costs, as many patents are thought to slow down research. This problem is described as "the problem of the anti-commons" (Heller and Eisenberg, 1999) or "patent thickets" (Shapiro, 2001; Pray et al., 2005). Consider the example of Veery wheat, which is the product of 3170 different crosses involving 51 parents from 26 countries that were globally, publicly released. The development cycle of Veery would have been very difficult if, for each parent and each cross, it was necessary to negotiate a separate agreement (SGRP, 2006). Even though IPR tends to be territorial, i.e. granted at the national level, trade agreements have led to greater 'harmonization' of IPR regimes (Falcon and Fowler, 2002) with countries adopting laws and rules that may not benefit seed-saving farmers (Box 2-3).

INSERT Box 2-3. Emergence of TRIPs-Plus.

In many developing countries, institutional infrastructure required for implementation and enforcement of IPR regimes is still lacking. Opposition against TRIPS and the IP-clauses of free trade agreements concentrates on the lack of incentives for development of the seed industry in developing countries due to the harmonization approach. However, in agricultural biotechnology development, which is highly concentrated, the IPR issues precipitate more in the form of licensing practices and policies, shaping the impact of patent systems to a large extent. Consequently, there has been a misconception that existing problems can be best solved through reshaping patent regulations and laws alone. There is a related need to examine how licensing agreements contribute to many problems at the intersection of IP and agricultural biotechnology (CIPP, 2004).

*Sharing of genetic resources; challenge and necessity. A reaction to IPR: national sovereignty and equity issues.* The lack of explicit rules governing germplasm rights was the historical standard in agriculture until the 1990's. As pressure to protect IPR in improved varieties and 'inventions' increased, the atmosphere concerning access to and use of genetic resources became increasingly politicized. This was augmented with concern, particularly among developing countries, that inequitable global patterns were established in the distribution of benefits associated with the use of genetic resources. Concurrently, there was growing concern that genetic diversity and local knowledge related to the use of those resources continued to be eroded under the pressures of modernization (Gepts, 2004).

In response, the international community attempted to address these tensions and create a new regime for access to genetic resources and the sharing of benefits associated with their use. One of the most significant outcomes was the Convention on Biological Diversity (CBD, 1994) (Box 2-4 and Chapter 7), which came into force in 1993. The CBD emphasized states' sovereign rights over their natural resources and their “authority to determine access to genetic resources, subject to national legislation.” The Convention also addresses rights of local and indigenous communities in this respect. Over 160 countries have ratified the CBD, the US is not among them. Most countries have interpreted the access and benefit sharing provisions of the CBD as the basis for establishing much tighter procedural and substantive restrictions to gaining access to genetic resources within their borders. To this end, they have developed, or are developing, bilaterally oriented access laws that require case-by-case negotiations to establish legal conditions for obtaining and using materials from a country although they are not binding, and few countries have reported implementing them. Nonetheless, they are a good indicator that most countries think of the CBD’s access and benefit sharing provisions as requiring, or justifying, a bilateral and restrictive approach to regulating access. Very different approaches were taken by individual countries to implement their sovereignty rights. Noticeably, the African Union and some countries in Asia (notably India and Thailand) have developed an approach that combines aspects of access and benefit sharing and breeder’s rights in one regulatory framework, thereby clearly indicating the connection between the two issues.

INSERT Box 2-4. Convention on Biological Diversity.

While a restrictive bilateral approach to implementing the CBD may be appropriate for wild endemic species of flora or fauna, it is not well suited to plant genetic resources for food and agriculture (Box 2-4). All domesticated crops are the end result of contributions of farmers from numerous countries or continents over extremely long periods of time. The CBD explicitly closed the concept of ‘heritage of mankind’ that had been expressed in the 1980’s. The nonbinding International Undertaking (Box 2-5) has re-established a commons for the crops and forages included in its Annex 1. CIP and IRRI have reported that since the CBD came into force, movement of plant varieties from and to their gene bank collections have been noticeably reduced and regulation of biological materials has resulted in increased bureaucracy and expense. Very few cases of effective (even non-monetary) benefit sharing as a result of CBD-based regulation during the first decade of the Convention (Visser et al., 2005). The key message is that promoting fair and equitable sharing of the benefits arising from the use of genetic resources remains a major goal. Defining a monetary value to estimate the historic or current contribution of farmers’ varieties remains elusive (Mendelsohn, 2000). Identifying the actual genetic resource property attributable to specific farming communities or even nations is “problematic” (Peeters and Williams, 1984; Visser et al., 2000). Some proponents have argued that benefit sharing would be more successful in the form of transfer of international capital, e.g. through development assistance to improve rural incomes in genetically diverse farming systems (Brush, 2005). Another approach could be to reduce structural adjustment policies that link agricultural credit to the planting of modern homogeneous varieties, and other crop and technology choices (Morales, 1991; Foko, 1999; Amalu, 2002).

*The question of facilitated access.* To match the principle of national sovereignty with the needs of sustainable agriculture and food security, an International Treaty for Plant Genetic Resources for Food and Agriculture concluded in 2001 and entered force in June 2004 (Box 2-5 and Chapter 7). With roughly the same objectives as the CBD, it translates its conservation and sustainable use goals to agriculture, including both *in situ*, on farm and *ex situ* conservation strategies, and various aspects of crop improvement by both farmers and specialized plant breeders in implementing ‘sustainable use’.

INSERT Box 2-5. International Treaty on Plant Genetic Resources for Food and Agriculture.

The main novelties in the International Treaty are (i) the creation of a Multilateral System for Access and Benefit Sharing for most important food crops and pasture species and (ii) the definition of the concept of Farmers’ Rights. Farmers’ Rights include the right of benefit sharing, of protection of traditional knowledge and of farmers’ involvement in relevant policy making. The objective is to have no restrictions on the ability of farmers to save, use, exchange and sell seed. However, signatory countries have freedom in specifying the Farmers’ Rights as “subject to national law and as appropriate.” The formulation was chosen to avoid conflict with existing and future IPR laws. Some claim that this formulation has thus far prevented an international acceptance of an inclusive Farmers’ Rights concept (Brush, 2005).

### 2.3.1.4. Increasing consolidation of the private sector.

*The changing face of the seed industry.* In the context of newly emerging IPR regimes and the development of biotechnology (e.g. identification, cloning and transferring of individual genes), a major theme of consoldiation in the agricultural plant biotechnology and seed industries has emerged (Pingali and Traxler, 2002; Pray et al., 2005). This consolidation significantly altered the course of germplasm management and marked a major shift in the relationship between the public and private sector.

Consolidation of the industry began with mergers of family-owned seed companies by multinational chemical firms to capitalize on synergies between seeds and chemical inputs (Thayer, 2001; Falcon and Fowler, 2002). Consolidation in the seed industry had been ongoing since the 1970s, but the unprecedented concentration in the 1990s resulted in an extreme vertical integration of the seed and biotechnology industries (Hayenga, 1998). This was followed by a horizontal integration of agriculture and pharmaceuticals into life sciences companies.

The first trend was driven by (i) the stagnation of the agrochemical sector; (ii) the changing knowledge base and innovations in chemistry and biotechnology; and (iii) the policy environment, such as the increased burden of regulations (Hayenga, 1998; Falcon and Fowler, 2002). Between 1995 and 1998, in the US alone, approximately 68 seed companies either were acquired by or entered into joint ventures with the top six multinational corporations (King, 2001). An analysis for thirty UPOV member-countries identified a high degree of concentration in the ownership of plant variety rights for six major crops at the national level in the developed world (Srinivasan, 2004). The area with the greatest concentration intensity in the past decades has been genetic transformation (Pray et al., 2005; Box 2-6). Liberalized foreign investment policies and multinational structure have allowed agribusiness companies to provide upstream research, with the local seed companies providing the crop varieties developed for specific geographical markets (Fulton and Giannakas, 2001). For developing countries, this concentration has implications for (i) the structure and autonomy of their domestic seed industries; (ii) their access to protected varieties; and (iii) the use of important breeding technologies (Srinivasan, 2004).

Recent research demonstrates that the effects of the increasing concentration of control over agricultural biotechnology has had mixed yield, economic, social and environmental effects in the United States, Argentina, South Africa, India and China (Fukuda-Parr, 2007), with the differences caused in part by differences in technology adopted, the structure of farming, the organization of seed markets and in the regulatory and institutional contexts. For instance, Emergent, the third largest cotton seed company in India was recently acquired by the US based Monsanto (ETC, 2005), yet India maintains substantial domestic seed company interests in GM technologies (Ramaswami and Pray, 2007). Agricultural liberalization in East Africa has led to an increase in the number of seed companies and varieties on the market but this has not led to an increase of maize yields or production per capita since the mid-1980s (De Groote et al., 2005).

Today, the top 10 agribusiness companies (all based in Europe, the US or Japan) represent half of the world’s commercial seed sales (ETC, 2005). These ten firms increased their control of biotechnology patents to over 50% in 2000 (Pray et al., 2005); indicating that instead of negotiating for the rights to a competitor’s technology, it might be simpler, cheaper, or more advantageous to acquire the competitor outright. Currently, patents on the foundational transformation technologies for grains are held by only three firms: DuPont, Monsanto, and Syngenta (Brennan et al., 2005).

INSERT Box 2.6 Emergence of genetic engineering.

*Implications of concentration.* A relatively stable market share may encourage corporations to invest in R&D, both in terms of current profitability and a reasonable expectation of future profitability. However, recent analysis suggests that we are seeing the beginning of negative impacts on innovation and competition through increased concentration within the private sector (Brennan et al., 2005). The major concerns are (i) industrial concentration reduces the amount and the productivity of research because R&D expenditures are consolidated and narrowly focused; (ii) concentrated markets create barriers to new firms and quell creative startups; (iii) concentration allows large firms to gain substantial monopolistic power over the food industry, making food supply chains vulnerable to market maneuvers (see 2.3.3; Pray et al., 2005). For instance, a recent USDA study suggests that consolidation in the private seed industry over the past decade dampened the intensity of research undertaken on miaze, cotton, and soybeans crop biotechnology (Fernandez-Cornejo and Schimmelpfennig, 2004). This raises concerns that decreasing levels of research activity would stunt agricultural innovations, and brings into question whether large biotech firms can be relied on to conduct research with an eye on the public good as well as their own profit margins (Pray et al., 2005). There is additional concern that the anti-competitive impacts of concentration have led to higher seed prices. USDA data suggest that cotton seed prices in the US have increased 3-4 times since the introduction of GM cotton and that GM fees have substantially raised the price of cotton seed in developing nations, such as India (Iowa State Univ., 2007).

*The dilemma of the public sector.* The establishment and strengthening of IPR in agriculture has contributed to a shift in emphasis from public to private breeding (Moschini and Lapan, 1997; Gray et al., 1999). The public research sector is increasingly restricted because fragmented ownership of IPR creates a situation wherein no comprehensive set of IPR rights can be amassed for particular crops. In 2003, the Public-Sector Intellectual Property Resource for Agriculture (PIPRA) regime was introduced by several US universities in collaboration with Rockefeller and McKnight Foundations with the goal of creating a collective public IP asset database. This collective management regime would allow public sector institutions to retain rights to use the newest and best technologies of agricultural biotechnology for the public good when they issue commercial licenses (Atkinson et al., 2003).

These creative IPR management regimes are needed for the public sector because many public breeding programs have been unsure of whether to complement or compete with the private sector; confusion has arisen as to how to take advantage of IPR to control the use of public material (Reeves and Cassady, 2002) or to capture royalties for bigger budgets (Fischer and Byerlee, 2002). These trends have triggered concerns that the lure of potential royalty revenue has distorted research priorities in public institutions away from poverty alleviation and sustainability, as has been suggested by research managers in Uganda (Louwaars et al., 2005) and the emergence of the so called 'University-Industrial Complex' in which universities are redirecting their research to meet the needs of sponsoring corporations (Press and Washburn, 2000). Historically, public sector institutions have been the dominant distributor and pre-breeder of germplasm (Morris and Ekasingh, 2001). In contrast, the growing private sector has focused on widely commercialized, competitive crops that are well protected by legal or technical IPR (Fernandez-Cornejo and Schimmelpfennig, 2004). This has meant that tropical crops, crops for marginal areas (and other public goods attributes, such as safety, health, and environmental protection), and "orphan crops" have remained outside the orbit of private investment (Naylor et al., 2004; Fernandez-Cornejo and Schimmelpfennig, 2004). This will remain a problem until an incentive is created for private firms to work on marginal crops or funding for these important crops is increased in public institutions.

### 2.3.1.5. Farmers, public and private sector: roles and relations

*Changes in funding and investments and the strengthening of the private sector vis à vis the public sector.* While global agricultural research investment has grown dramatically since the 1960's (more than doubling between 1976 and 1995), recent trends indicate a shift from public to private sector dominated research. The top ten multinational bioscience companies spend $3 billion annually on agricultural research while the global CGIAR system will spend just over $500 million in 2007 (see Chapter 8). The system has seen its funding decline over the last 15 years compared to the widening of its mandate to include NRM issues (Pardey and Beintema, 2001). Lack of funding for the CGIAR is expected to have negative consequences for NARS plant breeding, particularly in Africa as more than one-third of the approximately 8,000 NARS released crop varieties were based on IARC germplasm. Additionally, structural adjustment programs have severely affected the ability of developing countries to support their own public R&D budget (Kumar and Sidharthan, 1997; CIPR, 2002; Chaturvedi, 2008). A continued decline in public sector breeding (see Chapter 8), coupled with increased private sector growth will only increase the growing gap in research intensity between rich and poor countries.

*Emergence of new institutional arrangements. Public-private partnerships (PPPs) to reach development and sustainability goals*. The changing character of the seed industry has highlighted public/private partnerships as potential generators of valuable synergies (Table 2-5). Examples of PPPs that have positively affected small-scale farmers include hybrid rice development in India, insect resistant maize in Kenya, industry led associations to improve seed policy in Kenya and collaborative efforts to promote biosafety regulation in India (IFPRI, 2005).

INSERT Table 2.5. Public-private partnerships in the CGIAR.

Some PPPs have a strong charitable character; others include a clear, but often long term, commercial benefit to the private partner. However, to date few success stories of PPPs that are pro-poor have emerged, and even fewer examples have surfaced where partnerships have contributed to food security, poverty reduction and economic growth. Major constraints on PPPs have been identified, including (i) fundamentally different incentive structures between collaborating organizations; (ii) insufficient minimization of costs and risks of collaboration; (iii) limited use of creative organizational mechanisms that reduce competition over key assets and resources; and (iv) insufficient access to information on successful partnership models (see Spielman and von Grebmer, 2004). Creative IPR strategies may help in the establishment of public-private partnerships. Licensing of IP rights by private to public sector actors for humanitarian uses has facilitated technology transfer, e.g. rice rich in pro-vitamin A and Ringspot Virus Resistance for papaya Asia (Al-Babili and Beyer, 2005; Brewster et al., 2005). Partnerships can be successful as in the case of the Daimler Chrysler collaboration with Poverty and the Environment in Amazonia (POEMA) to use coconut fibers and natural latex rubber (Zahn, 2001; Laird, 2002). Additionally, a recent initiative, the Science and Knowledge Exchange Program, to exchange staff between the public and private sectors may effectively develop productive pro-poor partnerships in food and agriculture. In Africa, schemes have been put forward to promote the acquisition of private sector innovations by the public sector at a price based on their estimated value to society (Kremer, 2003; Master, 2003). Private companies would contribute to crop improvement through partnerships that use local varieties and provide source material and information for improved regulatory passage (Keese et al., 2002; Cohen, 2005). However for complicated genetic transformations, dozens of patents are involved in a single transformation (Guerinot, 2000). In this case, all public and private IPR holders must grant licenses to all IP involved in the final product (Al-Babili and Beyer, 2005). Experience suggests that the public sector must take the lead in such initiatives on crops that are essential for food security, but have marginal profitability.

*Renewed involvement of farmers in genetic resource management: Participatory Plant Breeding as a new arrangement.* Today, farmers remain indispensable actors in any regime that seeks to conserve, improve, and disseminate genetic diversity. It is estimated that 1.4 billion farmers save seed from year to year (Pimentel et al., 1992; Cleveland et al., 1994; Bellon, 1996). There are many advantages of *in situ* conservation, in particular the relationship between diversity and yield stability (Amanor, de Boef, and Bebbington, 1993; Trinh et al., 2003; Abidin et al., 2005). Participatory plant breeding and *in situ* management relies on the collaboration between farmer-breeders and corporate plant breeders (Lipton and Longhurst, 1989; Sthapit et al., 1996; Kerr and Kolavalli, 1999; Almekinders and Elings, 2001; Witcombe et al., 2005). Traditionally, these projects are judged on their ability to produce adapted crop material at lower costs than conventional programs and on their ability to produce higher genetic gains per year (e.g., Ceccarelli et al., 2001a, 2003; Smith et al., 2001; Witcombe et al., 2001; Virk et al., 2003, 2005). However, participatory research projects (comprised of both formal and informal actors) have also led to the spread of socially responsible, technical innovations and important policy changes (Joshi et al., 2007). These innovations have been shown to improve the welfare of the poor and socially excluded. One of the best examples is a 1997 client-oriented participatory crop improvement (PCI) project in Nepal in which there was formal recognition that informal R&D processes were taking place, and a move to encourage those processes (Biggs, 2006). This led to changes in National Varietal Release Procedures and to more effective collaboration between different actors. Informal developments were essentially legitimized and supported. Nevertheless, the benefits of farmer participation may not be universal, and adoption of participatory methods has not been as high as expected, notably because of methodological limitations to upscaling (Witcombe et al., 2005).

*The quality issue.* In developed countries, changes in the consumers' preferences have pushed the labeling of the geographical origin of products, along with the notion of “terroir”, with the result that farmers and specialized breeders are reviving old crop varieties (Bérard and Marchenay, 1995; Bonneuil and Demeulenaere, 2007). The development of organic and sustainable food production systems has created additional challenges, e.g., organic production must use seeds that have been produced in organic conditions. Instead of working on larger domains of breeding for conventional agriculture, breeders select for specific adaptability to specific environments and practices. All these trends challenge the classical ways of evaluating varieties. Since the multifactor and multi-site experimentation, backed by statistical analysis is more difficult to perform, new ways of assessing varieties and seeds are needed, e.g., simulation modeling (Barbottin et al., 2006). The key conclusion is that knowledge must be shared among different actors, including farmers, users and consumers. The overall globalization of markets is increasingly pushing this issue in developing countries that seek to cater to the needs of specific market niches in industrialized countries.

### 2.3.1.6. The need for a renewed design with distribution of diverse roles

Germplasm management over the last 150 years has been characterized by standardization and scale of economies. This has been paramount to the rapid spread and success of widely adapted germplasm. It resulted in seed management becoming largely separate from agricultural and cultural systems, with a decline in the number and diversity of actors actively engaged in seed systems. Moreover, the tightening of IPR, access and benefit sharing laws and other forms of controls over genetic resources weakened exchange of genetic resources among breeders.

Industrial strategies have been based on strengthened IP arrangements; attempts to balance IPRs with farmers, industry and the public sector has added to hyper-ownership issues. Consolidation of the seed industry has facilitated the spread of rapid technological advances, but not always to the benefit of the poor. The history of germplasm management has revealed shortcomings, specifically in social and ecological arenas.

Asymmetries in access to germplasm and benefit sharing have increased vulnerabilities of the poor. The International Treaty on Plant Genetic Resources is the first major international policy that attempts to proactively address the situation by creating a form of international germplasm exchange and research commons. Other initiatives such as Public-Sector Intellectual Property Resource for Agriculture (PIPRA) aim to create a collective public IPR asset database to allow the public sector to continue to develop public good germplasm. PPPs could lead to pro-poor advances if current challenges, such as minimization of risks of collaboration, are tackled. This assessment questions the current separation between researchers and farmers and calls for an increased role of user's knowledge in the design of innovation, as exemplified in participatory plant breeding. Local and diverse arrangements have been successful at meeting development and sustainability goals for germplasm management. These arrangements will be important for using germplasm to respond to the uncertainties of the future.

### *2.3.2 Pest management*

Multiple approaches to pest management have emerged in different places during different periods in history. Each has been upheld by distinctive organizational arrangements reflecting cultural values, societal norms and political and economic priorities of their time and place. Widely differing interpretations exist that make competing claims regarding the advantages and disadvantages of the range of options; other narratives may describe differently the identification and implementation of sustainable solutions in pest management. The following narrative emerged from analysis of publications of UN agencies, the World Bank, the CGIAR, universities, national IPM programs in numerous countries, and the work of physical and social scientists, researchers, private sector actors including agrochemical companies, and NGOs actively involved on the ground in pest and pesticide management programs.

#### 2.3.2.1 Chemical control

*Emergence of chemical control.* Chemical control had its roots in US and German chemical research before and after both World Wars and was driven by formal interagency collaboration between military and public sector chemists and entomologists (Russell, 2001). The emphasis on crop protection and risk minimization supported pest control, rather than management and pest eradication using synthetic chemicals (Perkins, 1982; Russell, 2001). The approach underpinned the priorities of industrial countries: maximizing food and fiber production, increasing efficiency and releasing labor to other economic sectors. Research and extension efforts directed at biological, cultural and mechanical management of risk dropped sharply at this time (Perkins, 1982; Lighthall, 1995; Shennan et al., 2005). The pesticide industry grew rapidly, initially financed through government contracts and then loans, a practice that necessitated constant product innovation and marketing to repay debts (Perkins, 1982). Significant concentration has occurred (DFID, 2004; UNCTAD, 2006); by 2005, the top six multinational pesticide corporations accounted for 75% of the US$ 29,566 million global pesticide market (Agrow World Crop Protection News, 2005; ETC, 2005).

National and global concerns over food security drove the further intensification of agricultural production and adoption of synthetic chemical pesticides across much of Asia and Latin America (Rosset, 2000). The CGIAR played a pivotal role in the Green Revolution that carried synthetic chemicals into widespread use in irrigated systems (see 2.1). Multilateral and bilateral donor and development agencies such as the World Bank, USAID and JICA provided direct or subsidized supplies of synthetic pesticides, sometimes tying agricultural credit to adoption of input packages inclusive of these chemicals (Holl et al., 1990; Hammond and McGowan, 1992; Jain, 1992; Korten, 1995; Clapp, 1997; Ishii-Eiteman and Ardhianie, 2002; USAID, 2004). Direct state intervention in some cases enforced pest control through calendar spraying regimes or established pesticide distribution systems to ensure product use (Meir and Williamson, 2005). Farmers received pest control advice from pesticide sellers and extension agents operating under T&V and similar state-directed systems. In some cases, government extension personnel served also as pesticide distributors (Pemsl et al., 2005; Williamson, 2005) to supplement low government wages. Smaller pesticide production and distribution companies grew rapidly in developing countries such as Argentina, India, China and South Africa, often producing cheaper but more hazardous pesticides than their multinational counterparts (Pawar, 2002; Bruinsma, 2003).

*Impacts of the chemical pest control approach.* The significant yield gains and achievements in food security obtained in many countries in the 1950s and 60s have been closely linked to the use of hybrid seeds, synthetic fertilizers and other inputs including pesticides and to high levels of political and institutional investment in public sector research and extension (Bhowmik, 1999; Evenson and Gollin, 2003a; Lipton, 2005). Yield losses owing to disease and weed infestations have been reduced through chemical pest control (Bridges, 1992; CropLife, 2005ab); animal health has improved where insect-vectored diseases have been successfully controlled (Singh, 1983; Windsor, 1992; Kamuanga, 2001) and soil resources have been conserved through no-till practices, which sometimes rely on herbicide use (Lal, 1989; Holland, 2004). Some have speculated that widespread famines and devastation of crops from outbreaks of disease and pests have been prevented (Kassa and Beyene, 2001); from an historical evidence-based approach it is difficult to assess the validity of these claims. As early as 1950, evidence of pest resistance to pesticides, resurgence where natural enemy populations had been destroyed and secondary pest outbreaks began to accumulate (Stern et al., 1959; Smith and van den Bosch, 1967; van Emden, 1974). Pesticide resistance (including cross-resistance to new products) became extensive and has been thoroughly documented in the scientific literature (MSU, 2000; Bills et al., 2003).

By the 1960s the adverse environmental and human health effects of pesticide exposure had become known. The impacts, widely documented in the scientific and medical literature and popularized (e.g., Carson, 1962), affected not only pesticide applicators but entire rural communities and diverse biota in aquatic and terrestrial ecosystems and watersheds (reviewed in Wesseling et al., 1997, 2005; Hayes, 2004; Kishi, 2005; Pretty and Hine, 2005; Relyea, 2005; USGS, 2006; Desneux et al., 2007). Acute poisonings by pesticide residues have had immediate adverse effects, including death (Chaudhry et al., 1998; Rosenthal, 2003; Neri, 2005). Social and environmental justice cases have been documented regarding the inequitable distribution of the benefits of chemical control (largely accruing to better resourced farmers and manufacturers) and the harms in actual conditions of use that are experienced disproportionately by the poor and disadvantaged and the “ecological commons” (Wesseling et al., 2001; Reeves et al., 2002; Jacobs and Dinham, 2003; Reeves and Schafer, 2003; Harrison, 2004; Qayum and Sakkhari, 2005). A significant portion of the chemicals applied has proved to be excessive, uneconomic or unnecessary in both industrialized (Pavely et al., 1994; Yudelman et al., 1998; Reitz et al., 1999; Prokopy, 2003; Pimentel, 2005) and developing countries (Ekesi, 1999; Adipala et al., 2000; Jungbluth, 2000; Sibanda et al., 2000; Asante and Tamo, 2001; Dinham, 2003; Nathaniels et al., 2003). Pesticide reliance has also been linked to agricultural deskilling (Vandeman, 1995; Stone, 2007), evidenced by subsequent erosion of farmers’ knowledge of crop-insect ecology and reduced ability to interpret and innovate in response to environmental cues at field level (Thrupp, 1990; Pemsl et al., 2005).

Chemical control remains the cornerstone of pest management in many parts of the world, sustained by its immediate results, the technology treadmill (see 2.1) and path-dependency (wherein a farmer’s accumulation of equipment, knowledge and skills over time conditions her potential to change direction). It is also upheld by the professional cultures and training of most advisory and extension programs (Mboob, 1994; Sissoko, 1994; Agunga, 1995; FAWG, 2001; Sherwood et al, 2005; Touni et al., 2007); the dominance of institutions promoting technology-driven intensification of agriculture; product innovations and marketing by the agrochemical industries (FAO/WHO, 2001; Macha et al., 2001; Kroma and Flora, 2003; Touni et al., 2007); and direct and indirect policy supports such as tax or duty exemptions for pesticides (Mudimu et al., 1995; Jungbluth, 1996; Gerken et al., 2000; Williamson, 2005). In recent years, leading agrochemical companies have integrated seed ventures and biotechnology firms, enabling them to establish synergies among key segments of the agricultural market. This trend is expected to continue and lead to increasing convergence between the segments, with possible inhibition of public sector research and of start-up firms (UNCTAD, 2006). The history of chemical control illustrates a phenomenon in agricultural science and technology development, in which early success of a technical innovation (often measured by a single agronomic metric such as productivity gains), when accompanied by significant private sector investment in advertising and public relations (Perkins, 1982) and by direct and indirect policy supports from dominant institutional arrangements (Murray, 1994), translates into narrowing of organizational research and extension objectives, widespread if uncritical grower adoption and delayed recognition of the constraints and adverse effects of the technology (e.g. resistance, health hazards, etc.).

### 2.3.2.2 Integrated Pest Management (IPM)

Integrated Pest Management (Box 2-7) in its modern form was developed in the 1950s in direct response to the problems caused by use of synthetic insecticides in actual conditions of use (Perkins, 1982). IPM took many forms but in general emphasized cultural and biological controls (Box 2-8) and selective application of chemicals that do not harm populations of pest predators or parasitoids (Stern et al., 1959), based on scientific understanding of agroecosystems described as complex webs of interacting species that can be influenced to achieve crop protection. IPM adoption in industrialized countries was stimulated by growing concern for human health and the environment, consumer desire for low or no pesticide residues in food (Williamson and Buffin, 2005) and public sector recognition that regulatory interventions were needed to remove the most harmful chemicals from sale. The spread of IPM in the South was driven by the high incidence of involuntary pesticide poisonings among farmers and farm workers through occupational exposure (Holl et al., 1990; Wesseling et al., 1993, 1997, 2002; Antle et al., 1998; Cole et al., 2002). Other drivers were state authorities' recognition of the high cost of pesticide purchase for poorer farmers and resulting problems of indebtedness (Van Huis and Meerman, 1997); the potential of new markets spurred by consumer demand for pesticide-free produce both in the North (IFOAM, 2003; Ton, 2003; Martinez-Torres, 2006) and in countries with growing middle class populations (e.g. Thailand, China, India); export requirements of Maximum Residue Limits; and international attention to issues such as pollution of drinking water, human rights to a safe home and workplace and biodiversity loss.

INSERT Box 2-7. Integrated Pest Management and Box 2-8. Biological control.

*Impacts of IPM paradigm.* IPM can deliver effective crop protection and pesticide reduction without yield loss (Heong and Escalada, 1998; Mangan and Mangan, 1998; Barzman and Desilles, 2002; Eveleens, 2004). The yield advantages of IPM have been particularly strong in the South and thus have significant policy implications for food security in developing countries (Pretty, 1999; Pretty, 2002, Pretty et al., 2003). The community-wide economic, social, health and environmental benefits of farmer-participatory ecologically-based IPM have been widely documented (Dilts, 1999; Pontius et al., 2002; Pontius, 2003; Braun, 2006; Braun et al., 2006; Mancini, 2006; Mancini et al., 2007; van den Berg and Jiggins, 2007), including measurable improvements in neurobehavioural status as a result of reduced pesticide exposure (Cole et al., 2007). Large-scale impacts on social equity have not yet been assessed but higher household income, reduced poverty levels and significant reduction in use of WHO Class 1 highly toxic compounds have been shown in some cases (FAO, 2005a).

Difficulties in measuring the cost-effectiveness of large scale farmer-participatory IPM has impeded wider adoption (Kelly, 2005) and raised questions about its fiscal sustainability as a national extension approach (Quizon et al., 2000; Feder, 2004ab). As acknowledged by the authors, these studies did not calculate the economic savings from reduced poisoning and pollution nor attempt to quantify non-economic benefits. An evaluation of IPM research in the CGIAR system points to the need for more comprehensive economic impact analyses that include these variables (CGIAR TAC, 2000). A recent meta-review of 35 published data sets on costs and benefits of IPM Farmer Field Schools has meanwhile substantiated their effectiveness as an educational investment in reducing pesticide use and enabling farmers to make informed judgments about agroecosystem management (van den Berg and Jiggins, 2007).

More widespread adoption of IPM as defined in the FAO Code of Conduct has been constrained by political, structural and institutional factors, principally

- limited capacity of extension services in both industrialized and developing countries in providing adaptive, place-based, knowledge-intensive ecological education and technical support in IPM (Blobaum, 1983; Anderson, 1990; Holl et al., 1990; Agunga, 1995; Paulson, 1995; Altieri, 1999; Norton et al., 2005; Rodriguez and Niemeyer, 2005; Touni et al., 2007);
- inadequate public sector and donor investment in IPM research and extension and poor coordination between relevant agencies (Mboob, 1994; ter Weel and van der Wulp, 1999; Touni et al., 2007);

- insufficient private sector interest in natural controls (Ehler, 2006) and widespread promotion of synthetic chemical controls by pesticide suppliers and distributors (Kroma and Flora, 2003; Touni et al., 2007);
- shifts in funding and research interests in agricultural colleges away from basic biology, entomology and taxonomy and limited resources for ecological investigations (Jennings, 1997; Pennisi, 2003; Herren et al., 2005); an incentives system that discourages multidisciplinary collaboration in pest management (Ehler, 2006); and a growing tendency, e.g. in the United States, to encourage research likely to return financial benefits to the university rather than broader benefits to the public or ecological commons (Kennedy, 2001; Berdahl, 2000; Bok, 2003; Washburn, 2005) while offering private sector partners such as the agrochemical/biotechnology industry a wider role in shaping university research and teaching priorities (Krimsky, 1999; Busch et al., 2004);
- vertical integration of ownership (FAO, 2003b) and concentration in private sector control (Vorley, 2003; DFID, 2004; Dinham, 2005) over chemical, food and agricultural systems, processes that tend to favor larger scale, input-intensive monoculture production over the biodiverse agroecosystems necessary to sustain effective performance by natural enemies; and
- inequitable distribution of risks and costs: in the absence of public sector support, farmers typically bear the upfront transaction costs and risks of conversion to pest management practices that serve the public good (Brewer et al., 2004; Ehler, 2006).

### 2.3.2.3 Institutional innovations and responses in pest management.

*Institutional innovations.* FAO's paradigm-shifting work in Asia provided (a) the scientific evidence that pesticide-induced pest outbreaks could contribute to crop failures while reduction of pesticide use could improve system stability and yields (Kenmore et al., 1984); (b) empirical evidence of the positive social impacts of field-based experiential learning processes (Matteson, et al., 1994; Mangan and Mangan, 1998; Ooi, 1998) and (c) the policy insight that a number of directives (e.g., ban of selected pesticides, removal of pesticide subsidies and national support for IPM) could transform the situation on the ground, as in Indonesia (Kenmore et al., 1984; Settle et al., 1996; Gallagher, 1999; Röling and van der Fliert, 2000). Building on FAO's Farmer Field School methodology (http://www.farmerfieldschool.info/), participatory field-based educational processes in IPM gained strength in the 1980s (Röling and Wagemakers, 1998). These innovations in knowledge, science, technology and policy subsequently led to an institutional innovation, the establishment of the Global IPM Facility (see 2.2) and the implementation of farmer-participatory IPM across Asia, Latin America, Africa and Central and Eastern Europe (UPWARD, 2002; Jiggins et al., 2005; Luther et al., 2005; Braun et al., 2006). Plant Health Clinics (piloted in Nicaragua, currently in use in 16 other countries), the combination of mass media campaigns, and farmer-to farmer extension and education (Brazil, Ecuador, Peru, Vietnam, Bangladesh) similarly have proven effective in promoting IPM. In Africa and Latin America, communities are exploring economic innovations in self-financing mechanisms for IPM field schools (Okoth et al., 2003).

Innovative agroenvironmental partnerships between growers, extensionists and IPM scientists have implemented integrated farming and alternative pest management strategies to reduce organophosphate insecticide use in major commodity crops across California (Warner, 2006ab) and implement resource-conserving IPM in Michigan (Brewer et al., 2004; Hoard and Brewer, 2006). Their success derives from collaborative partnership structures that emphasize co-learning models, social networks of innovation (through informal grower networks and supported by statewide commodity boards) and building capacity in flexible place-based decision-making rather than conventional transfer of technology (Mitchell et al., 2001; Getz and Warner, 2006; Warner, 2006ab).

*Policy responses. G*overnments have responded to the scientific evidence of adverse environmental and health effects of pesticides with legislation, regulatory frameworks and policy initiatives. A growing number of Southern governments have national IPM extension and education programs (Box 2-9), and several countries (Costa Rica, Ecuador, Paraguay, China, Thailand and Vietnam) have taken the lead in banning WHO Class 1a and 1b pesticides (FAO, 2006a). Various European countries have implemented Pesticide Use Reduction programs with explicit benchmarks for pesticide reduction (Box 2-9) and Organic Transition Payment programs (Blobaum, 1997). Domestic US programs emphasized IPM in the 1970s and 1990s but shifts in political priorities have led to uneven national support and a more narrow interpretation emphasizing pollution mitigation strategies over preventative approaches to ensuring crop health (Cate and Hinkle, 1994; GAO, 2001; USDA/NRCS, 2001; Brewer et al., 2004; Hammerschlag, 2007; see Hoard and Brewer, 2006 and Getz and Warner, 2006 for state-level innovations in IPM). The CGIAR has established an inter-institutional partnership to promote participatory IPM (http://www.spipm.cgiar.org). Bilateral donor agencies have also prioritized biocontrol or IPM in their development aid, e.g. Germany, the Netherlands, Sweden, IPM Europe and the United States (ter Weel and van der Wulp, 1999; SIDA, 1999; Dreyer et al., 2005; USAID, 2007). Maximum Residue Levels (MRL) regulations for pesticides in food have been established at national and international levels (see 2.3.3.). These and other international and national standards continue to undergo revisions in light of emerging scientific findings on possible and actual effects of low dose and chronic exposure to pesticide residues (NRC, 1993; Aranjo and Telles, 1999; Baker et al., 2002; Thapinta and Hudak, 2000; Kumari and Kumar, 2003; Pennycook et al., 2004).

INSERT Box 2-9. Policy instruments affecting pest management.

The UN FAO Code on the Distribution and Use of Pesticides (Box 2-9) focuses not only on minimizing hazards associated with pesticide use but also on promoting IPM. It indicates that "prohibition of the importation, sale and purchase of highly toxic products [such as] WHO Class I a and I b pesticides may be desirable" and recommends that pesticides requiring use of personal protective equipment (e.g. WHO Class II pesticides) should be avoided where such equipment is uncomfortable, expensive or not readily available (e.g. in most developing countries). In 2007, the 131st Session of the FAO Council mandated FAO to pursue a "progressive ban on highly toxic pesticides" (FAO, 2007). FAO has urged chemical companies to withdraw these products from developing country markets and is calling on all governments to follow the example of countries that have already banned WHO Class Ia and Ib pesticides (FAO, 2006a). Also in 2007, FAO hosted an international conference that highlighted organic farming's capacity to meet food security goals without reliance on chemical pesticides (Scialabba, 2007; Sligh and Christman, 2007). The FAO conference confirmed similar findings from numerous recent studies on organic agriculture (Parrott and Marsden, 2002; Pimentel et al., 2005; Badgley, et al. 2007; Halberg, et al., 2007; Kilcher, 2007).

The World Bank revised its pest management policy in 1998, in response to internal impact assessments (Schillhorn van Veen et al., 1997), public pressure (Aslam, 1996; Ishii-Eiteman and Ardhianie, 2002) and donor government concerns (e.g., Denmark, Germany, the Netherlands, Norway, Switzerland, United States). The policy now emphasizes "reducing reliance on chemical pesticides" and promoting "farmer-driven ecologically-based pest control" (World Bank, 1998a). Subsequent external and internal reviews of World Bank lending and project monitoring noted weak implementation of the Bank's IPM policy (Tozun, 2001; Ishii-Eiteman and Ardhianie, 2002; Hamburger and Ishii-Eiteman, 2003; Sorby et al., 2003; Karel, 2004) hampered by lack of trained staff and an organizational culture and incentive system favoring loan approval over project quality (Liebenthal, 2002). Recent analyses of written policy and project design documents suggest compliance may be improving (Karel, 2004; World Bank, 2005) and a detailed guidebook to support implementation of the Bank's IPM policy has been produced.

Significant international treaties (Box 2-9) are now in force that seek to minimize and eliminate hazards associated with pesticide use. Multistakeholder initiatives such as the Africa Stockpile Program have harnessed the energies of diverse stakeholders in reducing the hazards and risks of pesticides. Together these policy responses and international agreements, informed by scientific evidence and public participation, have enabled decisive and effective transitions towards more sustainable practice.

*Civil society responses.* Civil society has emerged as a powerful force in the movement towards ecological pest management, in Northern as well as Southern countries (e.g. India, Thailand, Ecuador, Philippines and Brazil). CSOs and independent researchers (as well as FAO, ILO, WHO and some governments) have called for a rights-based approach to agricultural development, that explicitly recognizes agricultural workers' and rural communities' rights to good health and clean environments (UN High Commission for Human Rights, 2001; Reeves and Schafer, 2003). NGOs working with social justice, environmental and health causes have contributed to national and international treaties and agreements on chemicals management, sustainable agriculture and food safety. Development NGOs (Thrupp, 1996), social movements such as the Brazilian Landless Workers' Movement (Boyce, et al. 2005) and farmer-NGO-scientist partnerships such as MASIPAG in the Philippines, CLADES in Latin America (Chaplowe, 1997a) and the Latin American Scientific Society of Agroecology (Sociedad Cientifica Latino Americana de Agroecologia or SOCLA) are implementing ecological pest management as a means towards achieving sustainable development goals. Like other development actors, NGOs have limitations in terms of impact, resources, capacity and performance; and accountability mechanisms have been weak (Chaplowe, 1997b). Nevertheless, important contributions to ecological pest management have resulted from NGO efforts (Altieri and Masera, 1993; UNDP, 1995; Chaplowe, 1997b; Altieri, 1999), although scaling up to achieve widespread impact, in the absence of broader policy reforms, remains difficult (Bebbington and Thiele, 1993; Farrington and Lewis, 1993; Farrington et al., 1993).

*Market responses.* There has been a notable rise in certification and labeling regimes to meet consumers' demand for information about the origins of foods and methods of production. Food retailers are responding by insisting on observance of legal MRL requirements and using pesticide residue data as marketing material. Food industry actors have focused on minimizing or eliminating pesticide use to meet consumer preferences and regulatory requirements and reduce business costs. Some agrifood companies and the US $30 billion food service company Sysco (Hammerschlag, 2007), food processors (e.g. tomato paste, coffee, cacao/chocolate) and some food retailers (Williamson and Buffin, 2005; EurepGap, 2007) have taken steps to source produce from suppliers—including thousands of small-scale producers—using IPM and organic methods. Labels identifying organic or low-pesticide production methods and other successful market-oriented collaborations (IATP, 1998) have encouraged growers to adopt these practices. Local food systems also offer a small but growing alternative to conventional crop production and distribution (Williamson and Buffin, 2005) (see 2.3.3).

*Response from pesticide manufacturers.* The multinational agrichemical industry has responded to global concerns about pesticides by developing less hazardous, lower dose and more selective pesticides, improved formulations, new application technologies and resistance management strategies (CropLife, 2003; Latorse and Kuck, 2006; Syngenta, 2006). These efforts can significantly reduce pesticide pressure on the environment, particularly in larger farm operations that can afford specialized equipment. Some pesticide manufacturers have formed Resistance Action Committees to assist advisors and growers in implementing pesticide resistance management practices (Jutsum et al., 1998). The Danish chemical company, Cheminova, submitted plans to FAO in 2006 to voluntarily phase out highly hazardous WHO Class I pesticides from developing countries by 2010 (FAO, 2006a). At the same time, public health specialists and development NGOs have criticized multinational pesticide companies for lobbying against stronger public health regulations, for failing to comply with national laws and the FAO Code of Conduct on the use and distribution of hazardous pesticides (Congress, 2002; Dinham, 2007), and in some cases for refusing to voluntarily withdraw recognized highly hazardous active ingredients—including WHO Class 1 pesticides and acutely toxic organophosphate pesticides—in developing countries (Rosenthal, 2003, 2005; Sherwood et al., 2005; Wesseling et al., 2005). Competitive pressure from local generic pesticide manufacturers that continue to produce off-patent pesticides can be a factor (EJF, 2002; Pawar, 2002).

Industry actors have developed their own IPM programs (Dollacker, 2000; CropLife, 2006). Many of these are built around continued or relatively small reductions in use of a company's pesticide products (Sagenmuller, 1999; Dollacker, 2000; Ellis, 2000; CropLife, 2003, 2005ab).

One explanation for this is that a company’s need to maintain economic returns on its investments renders them less likely to encourage substantial shifts towards pest management strategies that would significantly reduce reliance on their products (CGIAR TAC, 2000; FAO, 2001a; Murray and Taylor, 2001; Sherwood et al., 2005). Some newer products developed by private firms show potential to strengthen IPM efforts (for instance, synthetic pheromone products to be tried in the context of ‘push-pull’ strategies in Europe). Other programs describe the integration of crop productivity and biodiversity conservation efforts (Dollacker and Rhodes, 2007). Independent assessments of their effects in actual use, particularly in small scale farming conditions in the tropics, have not been made.

The multinational agrichemical industry has also launched ‘safe use’ programs to train farmers in the use and handling of pesticides and to ensure that products are used in a manner consistent with national regulatory frameworks (Syngenta, 2003; CropLife, 2005b). The efficacy of these pesticide use training programs is disputed, with some sources reporting considerable success

(Tobin, 1996; Grimaldi, 1998; Syngenta, 2006) and others finding no reduction in poisoning incidence among participating farmers (McConnell and Hruska, 1993; Murray, 1994; Kishi et al., 1995; Murray and Taylor, 2000). “Safe use” measures are often not affordable or feasible in tropical climates and under actual conditions of use in poor countries (Dinham, 1993, 2007; Cole et al., 2000; FAO, 2007). Even when pesticides are used according to label specifications, adverse health effects have been documented (Nurminene et al., 1995; Garry et al., 1996; Wargo, 1996; Schettler et al., 1996; Reeves et al., 2002). The industry’s overall contribution to broader equitable and sustainable development goals, particularly in developing countries, has not as yet been clearly demonstrated.

### 2.3.2.4 Overall assessment of trends and challenges in pest management

Despite the tightening national and international regulatory environment around synthetic pesticides and notwithstanding the documented success of ecological pest management in most crops and a fast-growing market for organic products, sales and use of synthetic pesticides is still growing, especially in developing countries. These trends continue to result in pesticide-induced pest outbreaks (Yudelman et al., 1998) and an unacceptably high level of unintentional pesticide poisonings under conditions of actual use, mostly but not solely in the developing world (Wesseling et al., 1993; Kishi, 2005, London et al., 2005). Public sector commitment to pesticide reduction efforts and investments in IPM and other ecological approaches has not been consistent over time (Cate and Hinkle, 1994). The prevalence of the use of synthetic pesticides today reflects their immediate results, path dependency at farm and institutional support levels, and the significant political and economic influence of agribusiness interests, trade associations and lobbying groups in the regulatory and policy arena (Ferrara, 1998; Rothstein et al., 1999; FAWG, 2001; Irwin and Rothstein, 2003; CAP/OMB Watch, 2004; Mattera, 2004; UCS, 2004; Dinham, 2005; Wesseling et al., 2005; Shulman, 2006; Hardell et al., 2007). This influence has sometimes downplayed research findings on harmful effects and weakened regulatory assessment of risks (Castleman and Lemen, 1998; Watterson, 2001; Hayes, 2004).

Scientific and technological progress has not been linear; successful pathways (e.g. in biocontrol) have gained and lost popularity according to the economic and political priorities of dominant institutional arrangements. Advances in ecological sciences (e.g. population, community, landscape ecology) have contributed to development of pest management options, but have been underutilized by most conventional extension systems. Genetically-engineered crops were expected by many to reduce the need for and therefore use of synthetic insecticides. However, their impact on both insecticide and herbicide use has been mixed, in some cases leading to increased recourse to synthetic controls. Their cultivation is perceived by some scientists and critics as potentially introducing new environmental hazards (Wolfenbarger and Phifer, 2000;

CEC, 2004; Donald, 2004; Snow et al., 2005), reducing efficacy of biocontrol measures (Obryki et al., 2002) or leading to adverse social impacts (de Grassi, 2003; Pengue, 2005; FOE, 2006) and health risks (Ewen and Pusztai, 1999; Prescott et al., 2005), constraining their adoption in sustainable development initiatives.

The central technical issue facing pest management today is no longer yield maximization, but long-term stabilization and resilience in the face of unknown and changing stresses (Reganold et al., 2001). New directions in science and technology can strengthen IPM efforts if the latter have a strong foundation in basic biology (entomology, botany, plant pathology, taxonomy, ecology), economics and the social sciences (CGIAR TAC, 2000). Agroenvironmental partnerships among farmers, extension agents and researchers that balance social and environmental learning (Warner, 2006b; Stone, 2007) and strengthen ecologically-informed decision-making capacities (Röling and Wagemakers, 1998; Getz and Warner, 2006; Warner, 2006a; Mancini et al., 2007; van den Berg and Jiggins, 2007) offer robust possibilities for meeting technical, social and institutional challenges in sustainable pest management.

Policy decisions in pest management knowledge, science and technology often have been implicitly or explicitly based upon perceptions of tradeoffs. The uneven distribution of gains and losses from these decisions reflect power asymmetries between competing actors (Krimsky, 1999; Kleinman and Vallas, 2001). They have fuelled social and political tensions; in some cases, these have contributed to the development of new institutional arrangements such as international treaties and conventions to manage pesticide problems. Dominant approaches to pest control have in many cases failed to ensure the now-recognized human right to a safe home and working environment (Fabra, 2002; Robinson, 2002; Reeves and Schafer, 2003). The evidence shows that if crop production is assessed solely by a simple economic metric, then other societal goals will not be properly valued. Informed decision-making in pest management requires integration of ecological and social equity metrics as well.

The policy and investment choices regarding pest management have significant implications for how successfully societies will respond to major global challenges ahead (associated with, e.g. clean water, climate change, biodiversity, etc). Responses are varied, reflecting the complex and sometimes competing interests of diverse actors. UN agencies such as the FAO, national governments, public health professionals, labor groups, NGOs, development experts and some private firms are working to eliminate WHO Class I and phase-out WHO Class II pesticides. Some pesticide manufacturers are developing new less toxic products and improved delivery systems, although many continue to sell and promote highly hazardous pesticides at the same time. Market leaders and innovators in the food industry are moving towards sourcing organic, fairly traded products. Governments, international commissions and initiatives such as UNCED (UNCED, 1993, and the UN IFCS (Box 2-9) use the precautionary and polluter pays principles in designing policy approaches to chemical use and distribution (EEA, 2001; City and County of San Francisco, 2007; Fisher, 2007). Scientists and researchers in the fields of public health, medicine, ecology and participatory development and extension call for greater public sector investment in agroecological research and education, and establishment of better institutional linkages among farmers, extension agents and physical and social scientists (UNDP, 1995; Wesseling et al., 1997; Röling and Wagemakers, 1998; SIDA, 1999; Sorby et al., 2003; Norton et al., 2005; Warner, 2006a; Cole et al., 2007).

The weight of the evidence points towards the need for more determined institutional and policy support for participatory ecologically-based decision making by farmers; agroenvironmental partnerships to foster social and environmental collaborative learning; stronger and enforceable policy and regulatory frameworks; and investments by public sector, donor and commercial agencies in sustainable and agroecological research, extension, education, product innovation and marketing. More experimentation is needed to develop and test institutional innovations that are likely to enable further societal shifts towards sustainable pest management.

### ***2.3.3 Food systems management***

Satisfaction of social needs and desires, and hunger, more than nutritional needs, govern the selection and consumption of foods). Different food systems differently affect food security, safety and sovereignty. Food systems (Fig. 2-4, 2-5) include the complex interactive and interrelated processes involved in keeping a community fed and nourished (Ericksen, 2006ab). At the core are food system activities that include production, processing, distribution, consumption and their outcomes: social welfare; food security and environmental welfare. A sustainable food system would incorporate social justice into a more localized system; alleviate constraints on people’s access to adequate, nutritious food; develop economic capacity to purchase local food; train people to grow, process, and distribute food; maintain adequate land to produce a high proportion of locally required food; educate people removed from food production, to participate in, and respect, its generation; and integrate environmental stewardship into process (Koc et al., 1999). Food systems are assessed at the local and global level here for the sake of simplicity, although more complex variations (e.g. regional systems) exist and much interaction actually occurs among all the levels.

Insert Fig 2-4. The food systems.
Insert Fig. 2-5. Food system activities and outcomes.

#### 2.3.3.1 Local food system activities

At the eve of World War II, local food systems (LFS) prevailed throughout the world. These predominantly fallow/rotational systems used manual labor (Mazoyer and Roudard, 2005), were family-owned, small and highly diversified crop-animal systems with varying productivity (Fogel, 2004; Mazoyer and Roudard, 2005). Food processing in many parts of the world relied on local knowledge of preservation and packaging techniques, such as salting, curing, curding, sun drying, smoking and fermentation (Bender and Smith, 1997; Johnson, 2000). Surplus produce was sold at the farm gate or in local market places directly to consumers or to intermediary traders (Amilien, 2005). LFS directly contributed to the incomes of small-scale farmers, providing fresh and culturally acceptable food to consumers, and allowing direct interaction between consumers and food producers. However, farmers and local processors often experienced high transaction costs, seasonal price highs and lows and flooded markets, while consumers often lacked choice and quality foodstuffs or encountered contaminated or unsafe products (Crosson and Anderson, 2002). Rural households primarily acquired food from their own production (from local markets, relatives and friends; or from gathering, hunting or fishing). LFS sustain livelihoods of a significant number throughout the world, particularly in the southern hemisphere.

#### 2.3.3.2 Global food systems activities

Over the past 50 years there has been a dramatic change in food systems particularly in developed countries (Knudsen et al., 2005; LaBelle, 2005) from local to global, traditional to an industrial, and from state regulated to a market- or transnational corporations-dominated system monopolized by relatively few companies from production to retail (Hendrickson and Heffernan, 2005). LFS production has changed for many into mechanized high-input specialized commodity farming, employing fewer people (Lyson, 2005; Dimitri et al., 2005; Knudsen et al., 2005). This transformation resulted in farm output growing dramatically, except in Africa (Knudsen et al., 2005) and a dramatic rise in GDP (Crosson and Anderson, 2002); spurring rapid growth in average farm size accompanied by an similar rapid decline in the number of farms and rural populations (Lyson, 2005; Knudsen et al., 2005).

Prior to the 20th century, increases in food production were obtained largely by bringing new land into production, With the exception of a few limited areas of East Asia, in the Middle East, and in Western Europe (Welch and Graham, 1999; Stringer, 2000; Knudsen et al., 2005). Science-based technology advancements by the end of the 20th century (Ruttan, 1990; Johnson, 2000; Khush, 2001) allowed consumers to spend a smaller portion of their income on food (Knudsen et al., 2005). Institutional factors like efficient marketing systems, dynamic production technology and higher education played equally important roles in generating long-term growth in agricultural output per hectare and person employed (Mellor, 1966; Hayami and Ruttan, 1985; Eicher and Staatz, 1998). Food processing and preservation involving new technologies such as cold storage; irradiation; high temperature treatments; chemical additives; canning; milling, labeling and sophisticated computer based controlled systems emerged, both creating and taking advantage of new mass markets. The advantages of pre-prepared time-saving food to rapidly urbanizing populations drove further innovations in food preservation. In OECD countries, a few international food processing giants controlled a wide range of well-known food brands, co-existing with a wide array of small local or national food processing companies. Globalized food trade was originally confined to commodities and non-perishables such as wine, salt, spices and dried fish but expanded to include a wide range of perishable foods transported, sold and consumed at long distances away from their production and processing locality (Young, 2004; Knudsen et al., 2005). Even consumers in rural areas became less dependent on food supplies from local farms and markets (Roth, 1999). Meanwhile, small food retail groceries merged or were swallowed by other emerging and increasingly powerful stores, chains and supermarkets (Smith and Sparks, 1993; Roth, 1999). In the USA for example, from 1990-2000, the market share of the meat industry held by the nation's top four retails rose from 17 to 34%. Institutional linkages within local food systems (Lyson, 2005) were thus broken and economies of scale increased by means of new institutional arrangements (Ericksen, 2006ab). Vertical integration in ownership of food supply chains (FAO, 2005c) and increasing concentration in private sector control over food systems (DFID, 2005) has been documented.

### 2.3.3.3 Food systems outcome trends

The globalized food system (GFS) is considered by some to be economically efficient and productive (Welch and Graham, 1999; LaBelle, 2005) and draws on a range of science, knowledge and technology that extends beyond the agricultural sector. The GFS however hides disparities among agricultural and food systems both in developed and developing countries (Knudsen et al., 2005; LaBelle, 2005). Concerns revolve around social welfare; food and nutritional security; food sovereignty, food safety and environmental welfare (Knudsen et al., 2005; Lyson, 2005) (Fig. 2-6).

Insert Fig 2-6. Potentially problematic social and environmental aspects of global food systems sustainability

*Social welfare:* The GFS widened the gap between the most productive and least productive systems: it increased 20-fold over the last 50 years, particularly between industrialized and developing countries[1] (Kinudsen et al., 2005; Mazoyer, 2005). Characterized by capital intensive AKST and seed/animal breeds that required high inputs and favorable agronomic conditions, the

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[1] With the exception of some portions of Latin America, North Africa; South Africa and Asia where it has been adopted by large national or foreign farms that have the necessary capital (Knudsen et al., 2005). Africa has the lowest production per unit area of land in the world (Wiggins, 2000; Paarlberg, 2002).

GFS favored farming populations with more resources (Knudsen et al., 2005; Lyson, 2005). There is some evidence that the Green Revolution, e.g., in Bangladesh, benefited the poor and the landless as well as those with resources and that small-scale farmers adopted faster than large scale farmers (Crosson and Anderson, 2002), but in many countries evidence demonstrates that better resourced individuals and firms benefited, sometimes at the expense of the poor and landless (see 2.2).

*Food trade:* The Uruguay Round of Trade Negotiations saw agriculture and food issues placed firmly within the WTO although some countries and organizations argued against their inclusion, maintaining that countries should have the right to determine their own policies on such an important issue as food security, i.e., they adopted a “food sovereignty” position (FOEI, 2001). Nonetheless, the 1994 WTO Agricultural Agreement adopted minimum import requirements and tariffs and producer subsidies that were accessible to transnational corporations both in USA and Europe (McMichael, 2001; Lyson, 2005), allowing them to operate economies of scale that lowered agricultural product prices all over the world (Welch and Graham, 1999; Wilson, 2005). Consumers and national economies benefited substantially from this agreement. These trends also opened up agricultural and food markets for the northern hemisphere commodities, with USA becoming the major exporter of cereals (with surplus being disposed of as food aid; Johnson, 2000) and Australia and New Zealand of dairy products. This development negatively affected local producers in developing countries; many countries, particularly in sub-Saharan Africa, became increasingly food importers (FAO, 2004). In developed countries, control of the food system became vertically integrated from seeds; production inputs; processing; transportation and marketing, forming food chain clusters (LaBelle, 2005; Lyson, 2005) and consequently, many small-scale producers lost their livelihoods (Watkins, 1996; Welch and Graham, 1999; Robinson and Sutherland, 2002; Wilson, 2005), migrating to towns where they faced new livelihood challenges and opportunities.

Insert Fig 2-7. A framework for understanding food security.

*Food security* (Box 2-10 and Fig. 2-8) greatly improved over the last few decades as a result pf the increase in global food production (Johnson, 2000; Crosson and Anderson, 2002) and the global grain trade (Johnson, 2000). Although increases in global food production (Paarlberg, 2002; Knudsen et al., 2005) surpassed population growth (Crosson and Anderson, 2002; Bruinsma, 2003; Knudsen et al., 2005), and was accompanied by an increase in the poorer country’s average food consumption, (Garrett, 1997; Izquierdo and de la Silva, 2000; Stringer, 2000; Johnson, 2000), food and nutritional insecurity persisted throughout the world even in countries which achieved *national* food security (Mellor, 1990; Stringer, 2000; LaBelle, 2005), particularly in sub-Saharan Africa (Wafula and Ndiritu, 1996; Knudsen et al., 2005).

Insert Box 2-10. Evolution of the term food security.
Insert Fig 2-8. Determinants of nutrition security: basic causes and links.

Protein energy malnutrition in developing countries declined from as high as 46.5% in the early 1960s to as low as 17% in the late 1990s (Khush, 2001; Young, 2004), with Africa contributing about a quarter (24%) of the total undernourished population globally (Young, 2004). This phenomenon corresponds with the proportion of those with prolonged deficits in required energy intake as chronic food shortages fell in Asia and Latin America except sub-Saharan Africa (FAO, 2001b; Lipton, 2001). In addition to other drivers (Johnson, 2000; Chopra, 2004), the failure of a Green Revolution in Africa (Crosson and Anderson, 2002) may partially be explained by the lack of improvement or worsening of the situation in Africa. Based on the Global Hunger Index (GHI)[2] (Weismann, 2006), 97 developing and 27 transitional countries exhibit poor GHI trends; the malnutrition hot spots are in South Asia and sub-Saharan Africa, where wars and HIV/AIDS exacerbate the situation.

The commoditized monocropping characteristic of the globalized food system (GFS) has resulted in a narrower genetic base for plant[3] and animal production (Knudsen et al., 2005; Lyson, 2005; Wilson, 2005) and in declining nutritional value (Welch and Graham, 1999; Kataki et al., 2001) and has negatively affected micronutrient reserves in the soil (Bell, 2004). A Mexican study, however, suggested that adoption of some improved varieties of maize had enhanced maize genetic diversity (Brush et al., 1988). Increasing and widespread micronutrient malnutrition has developed, affecting millions of people in industrialized and developing countries alike (Welch and Graham, 1999; Khush, 2001), with quantifiable costs through compromised health resulting from reduced productivity and impaired cognition (Welch and Graham, 1999). However, recent improvements are noted in some parts of the developing world (Mason et al., 2005). Meanwhile, elements of the GFS, for example, subsidies of commodity crops such as corn in the US (Fields, 2004), have contributed to often radical and rapid changes in dietary patterns characterized by an excess of highly refined carbohydrates, sucrose, glucose and syrups (ingredients in fast foods) and animal fats, with a parallel decline in intake of complex carbohydrates (Tee, 1999; Fields, 2004; Young, 2004). These changes, combined with a decline in energy expenditure associated with sedentary lifestyles, motorized transport and household domestic and work place labor-

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[2] GHI captures three equally weighted indicators of hunger: insufficient availability of food (the proportion of people who are food energy deficient); prevalence of underweight in children <5 years old; and child mortality (<5 years old mortality rate).
[3] Wheat, rice and maize account for account for the majority of calories in human diets.

serving devices (Young, 2004) have resulted in the emergence of obesity and other dietary-related chronic diseases afflicting both the affluent as well as the low income population in industrialized and developing countries (Tee, 1999; Fields, 2004; Young, 2004). This paradoxically co-exists with undernutrition (Young, 2004), signifying growing imbalances and inequities in food systems.

In the 1980s, food production shifted toward products that were convenient and served ethnic and health-based preferences. This shift has changed the structure of agricultural markets, further increasing specialization and prompting the emergence of contractual farming and vertical integration for supply and quality control, and development of special-use, high-value commodities (Barrett et al., 1999) particularly of farmed fish, livestock and specialty crop operations (Knudsen et al., 2005). Concerns have been raised regarding the impact of these structural changes on the rural poor (Lindstrom and Kingamkono, 1991; Welch and Graham, 1999; Grivetti and Olge, 2000) and marginalized urban populations.

*Food safety:* The right of everyone to have access to safe and nutritious food is reaffirmed by the Rome Declaration on World Food Security. Yet food-borne poisonings and illnesses represent a major daily health threat and results in significant economic costs in both developed and developing countries in spite of significant progress in the regulation of food standards, medicine, food science and technology (Box 2-11; FAO, 1999b).

The globalized food system, although it is subject to high controls and standards, can still threaten food safety, particularly for marginalized populations in industrialized and developing countries (Welch and Graham, 1999; Mol and Bulkeley, 2002). High-profile risks such as those associated with bovine spongiform encephalopathy (BSE); Belgian dioxin chickens; vegetables contaminated with Chernobyl nuclear fallout or with dioxins from waste-burning plants; and GMOs have been profiled in recent decades. Other environmental and health threats, less reported in the media, are also contributing to widespread concern about the GFS. As food passes over extended periods of time through the food production, processing, storage and distribution chain, control has become difficult, increasing the risks of exposing food to intentional, undetected or involuntary contamination or adulteration. The use of pesticides and fertilizers, the use of hormones in meat production, large-scale livestock farming, and the use of various additives by food processing industries are among the food safety concerns that are associated with the GFS. In developing countries, GFS safety concerns are compounded by rampant poverty negatively influencing policy compliance and poor infrastructure for enforcement of food control systems. Other threats to food safety in developing countries are offered by inadequate social services and service structures (potable water; health, education, transportation); population growth; high incidences of communicable diseases including Acquired Immunodeficiency Syndrome (AIDS);

competitive markets and trade pressures that may encourage short cuts that compromise food safety (CSPI, 2005).

Access to good quality food has been humankinds' main endeavor from the earliest days of human existence (FAO, 1999b) with governing authorities codifying rules to protect consumers from dishonest practices in the sale of food. The first general food laws in modern times were adopted during the second half of the nineteenth century; subsequently basic food control systems were established to monitor compliance.

Efforts to deal with hazardous agents (pesticides and food additives) began in the 1940s and 50s when toxicologists derived limits on exposure for protection of human health (Rodricks, 2001). A major step in advancing a science-based food safety system was the development and implementation of Hazard Analysis and Critical Control Point (HACCP) procedures in the food industry in the 1960s. In parallel, the development of “farm to fork” strategies by the industry extended the notion of quality management along the entire supply chain (Hanak et al., 2002).

Insert Box 2-11. Food-borne illnesses: Trends and costs.

Food contamination creates a social and economic burden on communities and their health systems. The market costs of contaminated commodities cause significant export losses (Box 2-11), while sampling and testing costs and costs to food processors and consumers can be high.

The incidence of food-borne diseases may be 300 to 350 times higher than the number of reported cases worldwide. Sources of food contamination may be either microbiological or chemical and may occur throughout the food chain, from the farm to the table. Risk, particularly in developing countries, is in part due to difficulties in ensuring that appropriate procedures are followed.

Microbiological contaminants, the most reported cause of food-borne illnesses, include bacteria, fungi, viruses or parasites (Box 2-12) and usually result in acute symptoms. Over the past few decades, the incidence of reported illnesses caused by pathogenic microorganisms in food has increased significantly.

Insert Box 2-12. Common microbiological contaminants in food.

Food-borne illnesses caused by chemicals are sometimes difficult to link to a particular food, as the onset of effects may be slow and hence may go unnoticed until permanent or chronic damage occurs. Contamination by pesticides, heavy metals or other residues intentionally or unintentionally introduced into the food supply, or introduced through poor post-harvest techniques leading to mycotoxins, are included in this category (Box 2-13). On the other hand, food poisonings can also be acute with immediate adverse effects including death, such as those caused by organophosphate pesticides (Box 2-13) (Kishi, 2005).

Insert Box 2-13. Chemical contamination of food: a few examples.

Food irradiation is another controversial food safety issue. Although useful in reducing the risk of microbial food-borne illness, the technology also destroys vitamins (OCA, 2006); affects taste and smell; poses dangers to workers and the environment; may create toxic byproducts; and has the potential for cellular or genetic damage. The European Commission heavily regulates irradiated foods and food ingredients (EC, 1999).

Recent trends in global food production, processing, distribution, and preparation are creating a growing demand by consumers for effective, coordinated, and proactive national food safety systems. Although governments play critical roles in protecting the food supply, many countries are poorly equipped to respond to the growing dominance of the food industry and to existing and emerging food safety problems. Fraudulent practices such as adulteration and mislabeling persist and can be particularly devastating in developing countries where 70% of individual income may be spent on food (Malik, 1981). The effectiveness of HACCP is limited to large scale firms (Unnevehr and Jensen, 1999; Farina and Reardon, 2000). Export safety standards are often higher than those applied to domestic products markets particularly in developing countries. In some cases, governments have shifted the burden of monitoring product safety to the private sector, and in so doing, have become at most an auditor of the industry's programs.

*Major institutional arrangements:* Codex Alimentarius Commission was created in 1963 by FAO and WHO to guide and coordinate world food standards for protection of consumer health and to ensure fair food trade (Heggun, 2001). Bodies that operate at regional levels include the European Food Safety Authority (EFSA); and US Food and Drug Administration (FDA). Codex food standards are considered vital in food control systems even in smaller and less developed countries. However, 96% of low-income countries and 87% of middle-income countries do not participate in the Codex actively and hence their priorities are not always reflected in the standards developed by Codex (http://www.codexalimentarius.net/web/evaluation_en.jsp). Recent findings on possible effects from low dose, chronic exposure to contaminants and development of the risk assessment procedures has led to on-going revisions of international and national safety maximum residue levels of agrichemicals in the US, EU and Codex.

*Food sovereignty:* Whereas food security focuses on access to food, the concept of food sovereignty encompasses the right of peoples and sovereign states to democratically determine their own agricultural and food policies. Many definitions have emerged since the 1990s (People's Food Sovereignty Network, 2002; FOEI, 2003; Chopra, 2004; Forum for Food Sovereignty, 2007). There is currently no universally agreed public policy and regulatory framework definition for the term food sovereignty (Windfuhr and Jonsén, 2005). However, most definitions share a common reference point, starting from the perspective of those actually facing hunger and rural poverty and developing a rights-based framework that links the right to food with democratic control over local and national food production practices and policies. The concept often focuses on the key role played by small-scale farmers, particularly women, in defining their own agricultural, labor, fishing, food and land policies and practices, in ways that are environmentally sustainable, and ecologically, socially, economically and culturally appropriate to their unique circumstances (http://www.foodsovereignty.org/new/). Proponents also contend that decentralized, diverse, and locally adapted food and farming systems, based upon democratic and participatory decision-making, can ultimately be more environmentally sustainable and equitable than a globalized food system lacking such features (Cohn et al., 2006).

Via Campesina, a global farmers' movement developed the concept in the early 1990s, with the objective of encouraging NGOs and CSOs to discuss and promote alternatives to neo-liberal policies for achieving food security (Windfuhr and Jonsén, 2005). The concept was publicized as a result of the International Conference of Via Campesina in Tlaxcala, Mexico, in April 1996. At the World Food Summit in 1996, Via Campesina launched a set of principles (Box 2-14) that offered an alternative to the world trade policies to realize the human right to food (Menezes, 2001; Windfuhr and Jonsén, 2005). In August the same year, reacting to the Mexican government's decision to increase maize imports from North American in accordance with the Free Trade Agreement (NAFTA), a large number of Mexican entities organized the *Foro Nacional por la Soberania Alimentaria*, underscoring the need to preserve the nation's autonomy in terms of defining its food policy (Menezes, 2001). Since then, a number of NGOs, CSOs and social movements have further developed the concept and its institutional implications (Menezes 2001; Windfuhr and Jonsén, 2005).

Insert Box 2-14. Via Campesina's food sovereignty principles. Source: Windfuhr and Jonsén, 2005.

The concept of food sovereignty introduced into debates on food security and international trade regulation the right of each nation to maintain and develop its own capacity (particularly of small-scale farmers) to produce food to fulfill its own needs while respecting agroecosystem and cultural diversity (Menezes, 2001) and ensuring sustainable access and availability of food in order to enable people to lead quality lives and exercise democratic freedoms (Rosset et al., 2006; Riches, 1997). Market-oriented globalization of economic activity is an important driver of change in the evolution of agricultural trade and food systems. The development of the right to food based on normative qualities is another driver but with markedly different characteristics. The efforts made over the last fifty years to express in international and national laws a series of universal rights, including the right to food, has been an explicitly moral enterprise that stands in contrast to the economic processes of market-driven globalization. The right to food was included in the Universal Declaration of Human Rights adopted by the United Nations in 1948, following Franklin D. Roosevelt’s speech in 1941 that captured the world by proclaiming freedom from want and fear; freedom of speech and faith (Oshaug et al., 1994). The UN Declaration on the Right to Development Act 2 (UN, 1986; General Assembly Resolution 41/128, New York) states that “… the human being, being central subject to development, should be the active participant and beneficiary of the right to development.” The various human rights instruments brought into force have created expectations and obligations for the behavior of individuals, social groups, and States (Oshaug and Edie, 2003). People are expected to be responsible for satisfying their needs, using their own resources individually or in association with others. States are expected to respect and protect the freedom of the people to make these efforts and the sovereignty over the natural resources around them, and are obliged to meet every individual’s right to food and nutritional security.

Successive efforts have been made to build such rights, expectations, and obligations into national laws and the governance of food systems. Norway has formulated food security and the right to food as the basis of its agricultural policy, strongly driven by consumer concerns. Brazil has extended the concept of cultural heritage under Article 215 of its Constitution to include food cultures. Both these efforts have had an explicit normative quality.

The concepts of economic, social and environmental sustainability as applied to food systems have been developed in processes of negotiation and intensive discussions that reflect contrasting political priorities and ideologies (Oshaug, 2005). The food sovereignty movement is increasingly challenged to actively develop more autonomous and participatory ways of knowing to produce knowledge that is ecologically literate, socially just and relevant to context. This implies a radical shift from the existing hierarchical and increasingly corporate-controlled research system to an approach that devolves more responsibility and decision-making power to farmers, Indigenous peoples, food workers, consumers and citizens for the production of social and ecological knowledge (Pimbert, 2007).

*Organic agriculture:* The term organic agriculture (OA) has evolved from various initiatives, including biodynamics, regenerative agriculture, nature farming, and permaculture movements, which developed in different countries worldwide from as early as 1924.[4] Since the early 1990s, OA has been defined in various ways. The most widely accepted definitions are those developed by IFOAM and the FAO/WHO Codex Alimentarius (Box 2-15). In response to the incipient marginalization of foods of local origin by supermarket chain developments; those dissatisfied with a globalizing food trade, desiring health foods or foods associated with cultural landscapes opened the way during the late 1950s and early 1960s for expansion of initiatives such as pick-your-own operations and farm stands that supported a slow growth in alternative marketing channels for farm goods on which organically certified food capitalized (Roth, 1999). Consumer demand for 'healthy' foods has begun to encourage large distributors and retailers also to integrate local and regional products into their offerings (Tracy, 1993; LaBelle, 2005).

Insert Box 2-15.

Emerging evidence (Bavec and Bavec, 2006) indicates that organic farmers are able to sustain their livelihoods and increase employment in local processing and marketing, thereby increasing community economic activity and incomes (FAO, 1999b; Parrot and Marsden, 2001; Halberg et al., 2007; Kilcher, 2007; Scialabba, 2007). OA systems rely on biological processes to improve soil fertility and manage pests and are often high in crop biodiversity (Roth, 1999). The resulting increased food variety and overall per-area productivity has led to diversified and increased nutrient intake and improved food safety and food security, particularly for Indigenous and resource-poor people (Roth, 1999; Scialabba, 2007; Sligh and Christman, 2007). Some studies, however, suggest that crop yields in organic farming are too low to sustain farmers' livelihoods and to produce quantities sufficient to meet growing and rapidly diversifying market needs (LaBelle, 2005) leading to concerns that more land would be needed if OA were to become widespread (Crosson and Anderson, 2002). These claims have been challenged by recent findings (Halweil, 2006; Badgley et al., 2007).

Technical challenges facing certified OA revolve around sourcing organically produced seed and fodder; consistent product quantity and quality; traceability; liability insurance of growers and processors; appropriate product attributes and pack size (LaBelle, 2005). More research is needed concerning the labor requirements of different OA systems. Labor demands in organic

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[4] Pioneered by a German philosopher Rudolf Steiner who theorized that a human being as part of a cosmic equilibrium has to live in harmony with nature and the environment (Stoll, 2002). Certification of biodynamic farms and processing facilities began in Europe during the 1930s under the auspices of the DEMETER Bund, a trademark chosen in 1927 to protect biodynamic agriculture.

farming could deter younger generations from farming, but unemployment could be alleviated, since the labor is more evenly spread over a growing season (Pimentel, 1993; Sorby, 2002; Granatstein, 2003; Pimentel et al., 2005). Commercial challenges include narrowing profit margins; regulatory overload; increased competition; and the need for constant innovations to stay ahead of consumer trends (Roth, 1999), as well as uncertain implications of large-scale corporate entry into the market. These questions have prompted FAO to propose a framework for socioeconomic analysis focusing on ecological, economic and social performance as an instrument for farmers and decision makers to understand the problems, tradeoffs and outcomes in alternative scenarios for a range of OA systems (Scialabba, 2000).

*Agriculture and human health:* The interrelations between agriculture and human health are complex (Fig. 2-9). The two are mutually and directly dependent on each others' status and performance. Agriculture contributes to good health through provision of food, fuel, fiber, fodder, materials for shelter and medicines. On the other hand, agricultural activities contribute to poor health through produce with nutritional deficiency; Food-borne diseases; food poisoning; chemical pesticide residues; and a range of occupational hazards (including, for instance, induced hazards such as schistosomiasis and malaria that may be induced by irrigation developments). Similarly, human health also affects agriculture either positively or negatively. It requires a healthy individual and society to generate a productive agricultural performance. Hence individuals or societies with poor health are unable to provide the necessary quality human input in agricultural activities, leading to poor agricultural productivity (quantitatively and qualitatively) and low incomes that in turn perpetuates poor health – a vicious circle.

Insert Fig 2-9. Linkages between agriculture and health.

The interrelationship between agriculture and human health is mediated by the natural environment, human culture and technological inputs. How to achieve equitable food production delivering optimum nutrition for health requires a better understanding of the interplay between agriculture and environment, culture, and technical capacity, and how this interplay changes over time (Lang, 2006; Snowden, 2006) (Table 2-6).

Insert Table 2-6. Health implications of agricultural and food revolutions.

## 2.4 Lessons from the Past: Implications for the Future

AKST encompasses different kinds of knowledge produced by numerous agencies and actors, notably but not only farmers. The complexity of the diverse and often unpredictable ways in which knowledge is generated justifies a systemic view of the processes involved in AKST. Well-evidenced but divergent and often conflicting interpretations exist of the contributions of AKST to such societal goals as increased productivity, environmental and social sustainability and equity as well as to societal knowledge about the damaging effects of agricultural technologies in different conditions of use. The resulting multiple narratives of past AKST processes and arrangements are not equally heard or recognized. Political power and economic influence has privileged some types of AKST processes, actors and institutional arrangements over others. Dominant institutional arrangements established the privileged interpretations of the day and set the agenda for searching for and implementing solutions.

The choice of historical narrative used to explain past events and the AKST options brought into farm practice has important implications for setting future priorities and projecting the future design of AKST. Special effort has been made here to render an account from differing perspectives of past and often yet unresolved controversies regarding AKST in order to present as comprehensive as possible an assessment of the effectiveness of different AKST systems in promoting innovations associated with a range of policy goals  Three main lessons regarding the effectiveness of AKST in relation to the combined goals of sustainability and development are drawn: the critical importance of partnerships, the crucial role of educating farmers in their vocation and the role of public policies and regulations.

### *2.4.1 Multiple AKST actors and partnerships*

In the prevailing AKST arrangements of the past key actors often have been excluded or marginalized. Preference has been given to short-term considerations over longer-term agroecosystem sustainability and social equity and to powerful voices over the unorganized and voiceless. Strong evidence shows that development of appropriate forms of partnerships can help bring in the excluded and marginalized and open AKST to a larger set of policy goals. A large number of effective participatory approaches exist that facilitate the establishment and operation of such partnerships. Targeted public support can help promote the use of these approaches and thereby address the biases in the hitherto dominant arrangements.

The Transfer of Technology (ToT) model, a supply-push approach, has dominated operational arrangements and policy thinking. Where the ToT model has been applied appropriately under the conditions of use necessary for achieving wide impact, it has been successful in driving yield and production gains. These conditions include properly functioning producer and service organizations, the social and biophysical suitability of technologies transferred in specific environments and proper management of those technologies at plot, farm and landscape levels. The implementation of the ToT model increased production at a faster pace than population growth in most developing countries, an achievement which did not appear likely thirty or forty years ago when the specter of famine and food crises loomed very large.

But AKST arrangements shaped by the ToT model have not been effective in meeting a broader range of goals associated with the multiple functions and roles of farm enterprises and diverse agroecosystems. Recognition of these limitations led to a growing awareness or rediscovery - documented by robust evidence - that innovation is a multisource process of demand-pull that always and necessarily involves a mix of stakeholders, organizations and types of knowledge systems. Effective innovation for combined sustainability and development goals has been led by farmers in association with a range of local institutional actors has occurred in both OECD and tropical settings. Multi-organizational partnerships for AKST that embraces both advanced scientific understanding and local knowledge and experimental capacities have led to the development and wider adoption of sustainable practices such as participatory plant breeding, integrated pest management, precision farming and multiyear nutrient management.

Agricultural and social science research and education offer examples of diverse partnerships with potential to advance public interest science and increase its relevance to equitable and sustainable development goals. A range of knowledge, science and technology partnerships among corporate actors in the agricultural and food industries, consumer organizations, NGOs, social movements and farmer organizations have pioneered ecologically and socially sustainable approaches to food and agriculture. Experience suggests that effective and enforceable codes of conduct can strengthen multi-organizational partnerships, preserve public institutions’ capacity to perform public-good research and mobilize private commercial capacity to serve sustainability and development goals.

### *2.4.2 AKST and education*

The ability of farmers and other actors to collaborate effectively in demand-pull partnership arrangements for the generation and implementation of AKST critically depends on the quality of the formal and informal education available to them. Basic and occupational education also empowers individuals and communities to drive the evolution of farming and build agroenterprises, adapt to new job opportunities and be better prepared for migration if necessary. Over the past decades various education and extension programs have enhanced farmers’ education through the integration of formal and informal AKST. Generally the most effective have built on local and indigenous knowledge and innovation systems, typically through participatory and experiential learning processes and multi-organizational partnerships. Proven options include but are not limited to experiential learning groups, 4-H clubs, farmer field schools, farmer research circles, participatory plant breeding, social forestry and related community-based forest landscape management, study clubs and community interaction with school-based curriculum development. Their gains at local levels often are undermined by higher level interests and by economic drivers.

Measures that remove or mitigate race, ethnic and gender biases that hamper the participation in educational opportunity of marginalized community members, diverse ethnic groups and women have been essential for local progress toward social equity but have not been widely adopted. Investment in the education and training of government policymakers and public agency personnel, particularly in decentralized participatory planning and decision-making and in understanding how to work effectively with rural communities and other stakeholders has also proven effective in promoting progress toward combined sustainability and development goals; broader issues of governance remain a concern.

More generally, experience shows that investment in science-informed, farmer-centered learning and in other rural actors' educational needs develops grassroots capacity to critically assess, define and engage in positive locally-directed development and the sustainable management of their environment. Modern ICTs are beginning to open up new and potentially powerful opportunities for extending the reach and scope of educational and interactive learning opportunities. Extension and advisory services complement but do not substitute for rural and occupational education.

### *2.4.3 Public policy and regulatory frameworks*

International agreements informed by scientific evidence and public participation have enabled decisive and effective global transitions toward more sustainable practices (for example, the Montreal Protocols, the Rotterdam and Stockholm Conventions, the FAO Code of Conduct, the EU Thematic on Sustainable Agriculture). However, new national, regional and international agreements will be needed to support further shifts towards ethical, equitable and sustainable food and agriculture systems in response to the urgent challenges such as those posed by the declining availability of clean water and competing claims of water, loss of biodiversity, deforestation, climate change, exploitative labor conditions.

Awareness of the importance of ensuring full and meaningful participation of multiple stakeholders in international and public sector AKST policy formation has increased over the period. For example, in some countries, pesticide policies today are developed by diverse group of actors including civil society and private sector actors, informed by science and empirical evidence and inclusive of public interest concerns. These policies—exemplified by the 2007 European thematic on IPM — focus on the multifunctionality of agriculture.

Three thematic narratives on the management of germplasm, pests and food systems illustrate the role of public policy and regulatory frameworks as key drivers of AKST.

- The number and diversity of actors engaged in the **management of germplasm** has declined over time, driven in large part by advancements in science, privatization of seed supply and more widespread recourse to various intellectual property regimes. This trend reduces the options available for responding to uncertainties in the future. It increases asymmetries in access to germplasm and increases the vulnerabilities of the poor. Participatory plant breeding provides strong evidence that diverse actors can engage in an effective practice for achieving and sustaining the broader goals of sustainability and development by bringing together the skills and techniques of advanced and conventional breeding and farmers' preferences and germplasm management capacities and skills, including seed production for sale. Further development and expansion would require adjustment of varietal release protocols and appropriate policy recognition under UPOV 1991.
- The debates surrounding the use of synthetic pesticides have led to new arrangements that have increased awareness, availability and effectiveness of the range of options for **pest management.** Institutional responses to evidence of harm caused by certain synthetic chemicals in actual conditions of use include the strengthening of regulatory controls over synthetic chemical pesticides at global and national levels, growing consumer and retail markets for pesticide-free and organic products, removal of highly toxic products from sale, development of less acutely toxic products and more precise means of delivery and education of users in safe and sustainable practices. What constitutes safe and sustainable practice has been defined in widely varying ways by different actors reflecting different conditions of use as well as different assessments of acceptable tradeoffs, between crop security, productivity and economic gain on the one hand and health and environmental protections on the other.

IPM exemplifies a flexible and wide-reaching arrangement of actors, institutions and AKST practices that better address the needs of diverse farmers and a more broadly acceptable balance of interests. Although definitions, interpretations and outcomes of IPM programs vary widely among actors, IPM typically incorporates KST from a broad range of sciences, including social sciences, and the experience and knowledge of a diverse set of actors. IPM has become standard practice in a number of high value production systems and has been adopted also by an increasing number of important commercial actors in food processing and retailing. Successful approaches to introducing IPM to small-scale producers in the tropics include farmer field schools, push-pull approaches, advisory services provided under contractual arrangements for supply to central processing facilities and creative use of communication tools such as short farmer-to-farmer videos and focused-message information campaigns. A combination of such approaches, backed by strong policy reform to restrict the sale of old-fashioned and highly toxic synthetic controls, will be needed to meet future development and sustainability goals. Further experimentation and operational fine-tuning of the institutional arrangements for IPM in the field in different settings is also needed. These can be evaluated by comparative assessment using a combination of social, environmental and economic measures that include both positive and negative externalities.

- **Food systems** have changed fundamentally over the last decades. Local food systems, known to sustain livelihoods at micro level, are currently challenged by globalized food systems that are evolving to meet urban demands. This trend brings opportunities but also threatens livelihoods and sovereignties of marginalized communities and indigenous peoples. Evidence based research has shown that social, ethical and cultural values in some countries can be integrated in the commercial mechanisms driving the evolution of food systems. Fair trade, territorial identities and ethnic labeling are among the options that can be considered by decision makers who wish to promote effective measures to protect the interests of the marginalized and revitalize rural livelihoods and food cultures. The promotion of geographic indicators can open development opportunities based on local resources and knowledge. They also offer opportunities for new agroenterprises such as tourism and specialty product development, as well as for collaboration with utilities such as water companies. Substantial evidence shows that production systems dominated by export markets can be weakened by erratic changes and price instability on international markets. Export-oriented food systems have sparked growing concern about the sustainability of long-distance food shipping and about the ecological footprint and social impacts of international trade in food products and agricultural commodities. Local consumption and domestic outlets for farmers’ products, often enhanced by the desire to sustain cultural identities associated with the consumption of products identified with their territorial origin, can alleviate the risks for food security and food sovereignty inherent in international trade.