Chapter 3

The Role of Research and Technology and Extension Services

Lead Article: THE ROLE OF RESEARCH, TECHNOLOGY AND EXTENSION SERVICES IN A FUNDAMENTAL TRANSFORMATION OF AGRICULTURE

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Abstract

The main challenges confronting sustainable agricultural knowledge, science and technology (AKST) development relate to achieving a transition from the conventional industrial agriculture model with its high external inputs and vested interests of the main players in supplying agricultural inputs, output processing and marketing. This requires political will on the part of policymakers to implement the new course of action suggested by several specialized institutions, including the IAASTD, UNCTAD, UNEP, UN-DESA and the High Level Panel of Experts on Food Security and Nutrition as well as by the recent FAO-OECD Expert Meeting on Greening the Economy with Agriculture, held in September 2011. There is ample evidence in these reports to justify new investments in AKST for sustainable agriculture. Pressure at the policy level is growing due to the series of food crises, both with respect to shortages and price increases, experienced over the past few years. The tendency remains strong to continue with business as usual, which aims at quick fixes and quick results.[1] If the repetition of the food crises that are becoming more frequent is any indication, then these quick fixes will run their course fast, with enormous negative social, environmental and economic consequences.

The case for a change in paradigm is well documented. Merely fine-tuning the present systems or redefining the status quo with new terms such as "sustainable crop production intensification" or "climate smart agriculture", among others, will not bring about the paradigm shift needed. To stop the "mining" of natural capital and, in particular, to drastically reduce GHG emissions from agriculture and make it more climate resilient requires a genuine, fundamental transformation backed by additional research. Agroecology has the proper foundations to support the needed transition from where we are today to where we need to be by 2050, with all our agriculture, whether it is small or large-scale, both at the local and global levels. Agriculture and farmers need to be among the key considerations of policymakers, as people may suffer from financial crisis but they cannot survive without food and water.

Agriculture should be top of the agenda in the debate on sustainable development and the green economy following the Rio+20 conference. It is only if agriculture, in its multifunctional role, takes centre stage that the other aspects of sustainable development will fall into place. The challenge for AKST is posed and the solutions for a new agricultural paradigm presented. It is now up to policymakers to swing into action. The time for more reports and debates on the merits of this or that technology has passed; we owe it to future generations to act now, and decisively, to safeguard our climate by building resilience and multifunctionality into our food systems to cope with the inevitable changes. These are the yardsticks against which we will have to measure progress towards sustainable agriculture. The AKST policies of tomorrow will need to address these challenges and develop the needed science, tools and criteria to implement the transition and measure progress.

A. Introduction

There is an imperative need for a fundamental change in the way the world grows, processes and consumes its food. As stated in the Report of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009), "Business as usual is not an option". What is meant by this is that in order to transform agriculture and the broader food system, agricultural knowledge, science and technology (AKST) need to be recast to address the past (unsolved), present and future challenges of food and nutrition security, poverty and hunger, and preserve rural livelihoods, health and the environment. The process that led to the IAASTD (also known as the Ag Assessment) and its implementation was unique in the sense that it included all stakeholders, from producers to consumers, as well as input suppliers and processors. The process was decided at the United Nations World Summit on Sustainable Development in Johannesburg in 2002, under a joint initiative of the World Bank and the Food and Agriculture Organization of the United Nations (FAO), and was supported by the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Health Organization (WHO) and the Global Environment Facility (GEF). This intergovernmental support gave the IAASTD the broad base needed to set the stage for changing the course of agriculture through a recasting of the AKST, or at least it was thought so, given that the report was ultimately also endorsed by 59 countries and welcomed by an additional three.

Since 2009, few AKST policies at the national, regional or international levels have actually changed. More reports have been written, mostly only to dilute the strong key messages of the IAASTD regarding the centrality of smallholder farmers who practice highly diverse forms of cultivation, the inappropriateness of an undue reliance on biotechnology and genetic engineering to solve the main problems of our agricultural and food systems, as well as the need to allow countries to choose their own agricultural trade, research and development (R&D) policies that suit their specific conditions and needs.

In 2008, the IAASTD already observed that what happens with AKST, and agriculture in general, in developed countries strongly affects what happens in developing countries, because of the highly interconnected world in terms of trade and knowledge exchange. It should be noted that while, overall, R&D in agriculture has diminished in importance over the past two decades, foreign aid is now on the rise again as a response to several food crises, although mostly in the form of quick fixes such as the provision of seeds, pesticides and fertilizers. Foreign aid continues to command large investments, mostly controlled and decided by developed countries, which still tend to consider their agriculture as the "role" model for developing countries. Unfortunately, there remains a tendency to increase short-term investments in quick fixes mostly after major catastrophes and food emergencies. Such actions, although needed in order to alleviate short-term humanitarian problems, seldom tackle the root of the perennial hunger problem, and merely provide a bridge to the next emergency. This form of aid is clearly inadequate for solving the causes of the repeated hunger and poverty problems; there is a need to rethink the overall approach to food security.

The IAASTD (2009) and UNCTAD (Hoffmann, 2011) as well as the High Level Panel of Experts on Food Security and Nutrition to the FAO Committee on World Food Security (CFS-HLPE, 2011) give a very good account of the magnitude of past investments in agricultural R&D at national and regional levels, as well as their sources, both public (i.e. by multilateral and member States of the Development Assistance Committee (DAC) of the OECD) and private. There was a slight decline of such investments until 2003, after which they started showing signs of recovery when developing-country governments began increasing their spending on agriculture, and DAC and multilateral aid agencies also increased the amount allocated to agriculture, both in total volume and as a share of official development assistance (ODA) (UN-DESA, 2011).

From the data provided in these reports, it is clear that there is a serious and urgent need to accelerate the modest upward trend in agricultural investments. As stated in the IAASTD report (2009), there is also a need to rectify the imbalance in the sources of funding by substantially increasing public support to AKST, both in developed and developing countries, since the research is supposed to deliver common public goods. This would help counteract the trend in private investments which emphasizes a narrow approach that tends to focus largely on promoting plant breeding, biotechnology and genetic engineering as solutions to the problems of climate change adaptation and mitigation, food security, hunger and poverty, rural livelihoods and the associated health and environmental problems. However, the complexity of the agricultural and wider food systems urgently requires an upgrading and change of course away from the reductionist approach to problem solving. The far more socially, environmentally and, ultimately, economically rewarding route of investing in smallholder and family-run agroecological farming systems does not receive the attention it deserves.

The fundamental issue in agriculture today is not that there is too little food produced; after all we produce an average of 4,600 kcal per person/day – roughly double the amount needed for healthy nutrition. A number of issues linked to this overproduction need to be addressed through new AKST policies:

- Only a few commodities make up the bulk of global food production, which does not satisfy the need for more diverse and localized production of quality and affordable food;
- The excess food is produced mostly in industrialized countries (with some developing-country exceptions such as India) with the help of price- and trade-distorting subsidies and at great social costs;
- The excess food is produced also at great environmental costs, contributing between 47 and 54 per cent of the total greenhouse gas (GHG) emissions that are partly responsible for climate change (see the comment of GRAIN in chapter 1 of this Review).
- Animal feed production, particularly cereals for ruminants, has a negative impact on animal and consumer health (due to meat quality, and antibiotic and hormone residues), and on the environment through carbon cycles when feed is transported around the world. There is also the environmental problem of animal factories which needs to be overcome, along with an emphasis on animal welfare, climate change and human health considerations.
- Consumption of biofuels, in the form of cereals and vegetable oils, should be reassessed and policies revised to reverse the strong growth of such consumption, which is clearly unsustainable. Besides, some observers have found no evidence of added benefits of biofuels in terms of lower GHG emissions, but they do affect food prices negatively (CFS HLPE, 2011; Lagi et al., 2011).

The shift in AKST investments at international, regional and national levels therefore needs urgently to address these fundamental issues, as suggested both by the IAASTD and more recently by UNEP (2011).

In 2003, member States of the African Union committed to spend 10 per cent of their national budgets on agricultural development. So far, only a handful of them are meeting this laudable target. That decision was made based on the recognition that it is in each country's best interest to have a strong agricultural sector, backed by a well-developed research and extension capacity. The latest food crisis in the Horn of Africa may yet give more credence to the need for urgent action, in particular to develop sustainable solutions to the increasing impacts of climate-change-induced phenomena, such as those caused by El Niño and la Niña.

The United Nations Conference on Sustainable Development – Rio+20 – held in June 2012 was another good opportunity to strongly commit to a new agricultural and food system along the lines of a multifunctional agricultural system, as defined in the IAASTD report. As Hoffmann and GRAIN illustrate in chapter 1 of this Review, agriculture is strongly implicated as part of the climate-change problem. It must therefore also be part of the solution. Enormous health problems have arisen from "modern diets" of highly processed and chemical-laced foodstuffs, not to mention the ecological impacts of existing conventional food production systems that overuse water, fertilizers and other fossil-fuel-based inputs, and are therefore, by definition, unsustainable. Furthermore, the so-called conventional/industrial agriculture is supported by perverse subsidies in developed countries that reinforce unsustainable practices, on the one hand, and overconsumption and waste on the other. In developing countries, farmers trying to compete with these subsidized products are forced to cut corners and exploit their natural resources. Due to poor investment in agriculture, these farmers suffer from a lack of knowledge exchange and insufficient or a complete absence of investment capacity to innovate and purchase miscellaneous inputs, including information and equipment. Moreover, they do not benefit from insurance schemes. Agriculture everywhere is a rather risky business which needs to be backed by insurance schemes to assure farmers their survival in bad years, which are becoming more regular events as climate-change impacts increase.

The transition from an energy-intensive form of agriculture, be it by importing the inputs or producing them locally, to a system that builds productive ecosystem services to sustain multifunctional, sustainable, resilient, viable and equitable agriculture requires major new investments in institutions and infrastructure. This inevitably requires the creation of new research centres and initiatives, which should be dedicated to research, education and extension under a fully participatory system that will also favour women and cover ecosystem services, organic farming, agroecology and agroforestry. The ultimate aim of those centres and initiatives should be the transformation of the present agricultural research system at national, regional and international levels to cater to the needs of a new agricultural paradigm (see the comments of Reij in this chapter and of Altieri and Koohafkan in chapter 1 of this Review). Technological and scientific innovations should respond to the needs identified by the end-users to meet the goals of multifunctional agriculture, instead of driving those needs.

Contrary to many preconceptions, agroecology is not the low-productivity system of our ancestors; rather it is a modern, knowledge-based, science- and technology-empowered food, fibre and fodder production system, and it is the only one capable of assuring food security in the medium and long term (see also the comment of Nemes on the productivity and profitability of organic agriculture in chapter 1). The merging of knowledge with technology and science to create innovations that address the broad range of issues in a systemic manner, in contrast to the reductionist approach that promotes biotech and genetic engineering industries, needs to be strongly promoted through public sector investments. Areas that require special and increased attention are soil sciences for the restoration, building and maintenance of soil fertility without the massive input of synthetic fertilizers, the development of mixed cropping and animal husbandry systems within rotation patterns that favour healthy plant growth, first line of defense for pest and disease control, and the production of quality plant and animal products that improve the health of consumers and the environment. AKSTs that fulfil these criteria are holistic in nature, take a landscape or river-basin view and emphasize the sustainable utilization of biodiversity, water, soil and energy within the agroecosystems.

In an effort to evaluate the feasibility of sustainable "green" agriculture to deal with the problems and challenges that lie ahead, while providing the needed food and nutrition security for the projected 9 billion people by 2050, UNEP (2011) sought to examine how green investments would help achieve greater economic, environmental and social sustainability. Following the *Stern Review*'s (2007) recommendations to invest an extra 1 or 2 per cent of gross domestic product (GDP) in a green economy, two scenarios were identified, using the Millennium Institute's T21 system dynamics model, in which the suggested additional investments in green agriculture would be undertaken globally.[2] In the first scenario (G1), an additional 0.1 per cent of GDP would be invested in green agriculture annually (equal to $118 billion – in constant 2010 dollars) between 2011 and 2050. In the second scenario (G2), 0.16 per cent would be invested in green agriculture annually (equal to $198 billion) during the same period. These additional investments would be undertaken in equal one-fourth measures in the following four activities along the lines suggested by the IAASTD (2009):

- Promoting sustainable agricultural management practices (i.e. environmentally sound practices such as no/low-tillage and organic agriculture);
- Minimizing pre-harvest losses through training and pest control activities;
- Developing or improving food processing for the prevention of post-harvest losses and better storage, especially in rural areas;
- Supporting research and development in agronomy, photosynthesis efficiency, soil biology and fertility (to close the yield gap), adaptation to climate change through biological processes and new crops, and for efficiency improvements in energy and water use.

It should be noted that R&D implies the participation in research and knowledge dissemination of the different stakeholders, in particular farmers – who are often women – in developing countries. UNEP (2011) shows that investments in sustainable agriculture can meet the need for food security in the long term, while reducing agriculture's carbon footprint, thereby making it part of the climate change solution. The modelling results summarized in table 1 are in line with the expectations of a new agricultural paradigm and the findings of many organic and agroecology case studies. They show that not only food security, but also environmental and social goals, can be achieved with a sustainable and resilient agricultural system.

In table 1, the "green scenario" (G2) is compared

Table 1: Green scenario 2: Impact of green investments in agriculture (amounting to 0.16 per cent of GDP)

Year	2011	2030		2050	
Scenario	Base year	Green	BAU[a]	Green	BAU[a]
Agricultural production ($ billion/yr)	1,921	2,421	2,268	2,852	2,559
Crops ($ billion/yr)	629	836	795	996	913
Livestock ($ billion/yr)	439	590	588	726	715
Fisheries ($ billion/yr)	106	76	83	91	61
Employment (millions)	1,075	1,393	1,371	1,703	1,656
Soil quality (Dmnl)	0.92	0.97	0.8	1.03	0.73
Agriculture water use (KM3/yr)	3,389	3,526	4,276	3,207	4,878
Harvested land (billions of ha)	1.2	1.25	1.27	1.26	1.31
Deforestation (millions of ha/yr)	16	7	15	7	15
Calories per capita/day (kcal) available for supply	2,787	3,093	3,050	3,382	3,273
Calories per capita/day (kcal) available for household consumption	2,081	2,305	2,315	2,524	2,476

Source: UNEP, 2011.
Note: [a] BAU= business as usual (scenario).

with a "business-as-usual" (BAU) scenario, where the same amount of additional investment, equalling 0.16 per cent of GDP/year, is made in conventional and traditional agriculture over a 40-year period. The results are impressive, and although these are compiled on a global scale, the basic principles also apply to the investments made to facilitate the transition towards multifunctional and sustainable agriculture that adopts traditional and low-input techniques as currently practiced in most developing countries by small-scale farmers as well as by some larger scale operations. Overall, these investments will lead to improved soil quality, increased agricultural yield and reduced land and water requirements. They will also increase GDP growth and employment, improve nutrition and reduce energy consumption and carbon dioxide (CO_2) emissions.

B. Agricultural production and value added

In the green scenario, total agricultural production (i.e. agricultural products, livestock, fisheries and forestry) would increase significantly compared with the BAU scenario. This change would be driven by increased crop production that would be capable of meeting the needs of a growing population projected to reach over 9 billion by 2050. Similarly, value added in agricultural production would increase by more than 11 per cent compared with the BAU scenario. It is important to note that despite an increase in agricultural production and value added, there would be no increase in the area harvested, while deforestation rates would be halved and water-efficiency increased by one third. This suggests positive synergies between investments in ecological agriculture and forest management.

C. Livestock production, nutrition and livelihoods

Additional investments in green agriculture would also lead to increased levels of livestock production and rural livelihoods, and improved nutritional status. Such investments are projected to lead to growth in employment of about 60 per cent compared with current levels, and to an increase of about 3 per cent compared with the BAU scenario. The modelling also suggests that investments in green agriculture could create 47 million additional jobs compared with BAU over the next 40 years. The additional investments in green agriculture could also lead to improved nutrition as a result of enhanced production methods. Meat production would increase by 66 per cent due to additional investments between 2010 and 2050, while fish production would be 15 per cent below 2011 levels and yet 48 per cent higher than the BAU scenario by 2050. Most of these increases would be the result of greater outlays for organic fertilizers instead of chemical fertilizers, and reduced losses because of better pest management and biological control.

D. GHG emissions

Total CO_2 emissions in the agricultural sector are projected to increase by 11 per cent relative to 2011, but will be 2 per cent below BAU. While energy-related emissions (mostly from fossil fuels) are projected to grow, it is worth noting that emissions from (chemical) fertilizer use, deforestation and harvested land would decline relative to BAU. When accounting for carbon sequestration in the soil from ecological practices, and for synergies with interventions in the forestry sector, net GHG emissions would decline considerably. These reductions would not be sufficient, however, and would need to be substantially stepped up to make agriculture GHG-neutral. Depending on how the GHG emissions are calculated, at production or food system level, the reduction would have to be between 30 and 50 per cent of the emissions resulting from present day agricultural practices, just to stay at 450 parts per million (ppm) of CO_2. This, by any measure, is still too high and risks continuing to expose ecosystems to irreversible damages. It is therefore necessary to take a much more bold approach to transitioning towards organic and similar agricultural practices that are able to absorb three to four times as much CO_2 as conventional and industrial practices before saturation occurs within some 50 years (IAASTD, 2009).

Agriculture therefore undoubtedly represents the lowest hanging fruit for climate change mitigation by simply doing what we already know how to do, and at little costs for the transition. In addition, the transition would be accompanied by a number of windfalls, from a substantial reduction in health-care costs due to healthier eating and living habits to a drastic reduction of ecosystem service costs and substantial savings from stopping perverse subsidies. Thus a transition to organic/agroecological farming practices should be the absolute priority when investing in AKST and new agricultural practices.

Overall, combining these results with research from other sources presents the following results:

- Returns on investments in "brown" agriculture will continue to decrease in the long run, mainly due to increasing costs of inputs (especially water and energy) and stagnating/decreasing yields.
- The costs of negative externalities of "brown" agriculture will continue to increase gradually, initially neutralizing and eventually exceeding any economic and development gains.
- Greening agriculture and food distribution will result in more calories per person/day, more jobs and business opportunities – especially in rural areas – and greater market access opportunities, especially for developing countries.

While each of the proposed measures will contribute to the shift towards a greener agricultural sector, the combination of all these interrelated actions will yield additional positive synergies. For instance, investment in more sustainable farming practices will lead to soil conservation, which would increase agricultural yield in the medium to longer term. This would allow more land for reforestation, which in turn would reduce land degradation and improve soil quality.

Looking at the key issue of resilience needed in the years ahead to deal with the challenges of climate change, in particular in developing countries that will be affected much more than developed countries, investment in AKST will need to be well above the level indicated in the *Stern Review*, given that there is the need to allow for a catch-up period of at least 20 years to adapt the research systems (universities, national and regional) to the needs of small-scale farmers who are practicing sustainable agriculture. Also, the enormous diversity in most tropical and sub-tropical agricultural systems adds to the need for decentralization of the research and the accompanying measures, such as knowledge and information dissemination.

E. Enabling conditions

Despite the clear logic and economic rationale for moving more rapidly towards sustainable agriculture, the transition will require a supportive policy environment and enabling conditions that could help level the playing field between conventional and sustainable agricultural practices. In particular, large investments in rural infrastructure, including roads, power, internet access, access to health care and quality schooling, as well as investments in non-farming but agriculture-related jobs, are essential for maintaining the rural areas as lively, interesting and rewarding places so as to keep the youth from migrating to the ever-growing urban slums.

F. The way forward

Implementation of the key findings and options for action of the IAASTD report will make agriculture part of the climate-change solution. It will also assure sustainable quality and quantity of food production to nourish the growing and more demanding population while supporting strong rural development in agriculture-related jobs.

The groundbreaking findings of the IAASTD process need to be internalized and translated into plans that can be implemented by the relevant government agencies responsible for AKST, as well as by national and international development agencies and non-governmental organizations (NGOs). The IAASTD report needs to be seen as the basis for action and for developing a genuine multifunctional agricultural system. New assessments need to be done at the global and regional levels to update the original report, complement gaps and take into account new social, environmental and economic developments. Assessments also need to be conducted at national levels, as recommended by the IAASTD (2009), as agricultural policies are very much a national issue, and also because agriculture is highly local. A review of the reports on agriculture that have been published since the release of the IAASTD report series, *Agriculture at a Crossroads,* in 2009, have added little except confusion to the call for a change in paradigm and to the assertion that business as usual is no longer an option. The funds and valuable expert time spent on rewriting and, more often than not, diluting the strong original message for a transition to multifunctional agriculture along the lines of agroecology, for example, could have been better used to start implementing it instead.

The main expected outputs from implementing the IAASTD options for action at research, development and extension policy level, as in the green scenario which the Millennium Institute developed for UNEP (2011), may be summarized as follows:

- *Green agriculture is capable of nourishing a growing and more demanding world population at higher nutritional levels.* An increase in food energy consumption from today's 2,100 kcal per person/day to around 2,500 kcal by 2050 is possible with the use of knowledge, science and technology in support of agroecology. It is possible to gain significant nutritional improvements from an increase in quantity and diversity of food (especially non-cereal) products. Public, private and civil society initiatives for improving food security and social equity will be needed to enable an efficient transition at the farm level, and to assure a sufficient quality of nutrition for all during this period.
- *Agroecology can significantly reduce poverty and the associated negative social and environmental impacts.* For every 10 per cent increase in farm yields, there has been a 7 per cent reduction of poverty in Africa, and more than 5 per cent in Asia. An increase in overall GDP derived from an increase in agricultural labour productivity is, on average, 2.5 times more effective in raising the incomes of the poorest quintile in developing countries than an equivalent increase in GDP derived from an increase in non-agricultural labour productivity. Evidence suggests that the application of green farming practices has increased yields by 54–179 per cent, especially on small farms.
- *A transition to agroecology provides significant environmental benefits.* Agroecology-based food production has the potential to rebuild natural capital by restoring and maintaining soil fertility; reducing soil erosion and inorganic agrochemical pollution; increasing water use efficiency; decreasing deforestation, biodiversity loss and other land-use impacts; and significantly reducing agricultural GHG emissions. Importantly, green agriculture has the potential to transform agriculture from being a major emitter of GHGs to one that is net GHG-neutral – and possibly provides even a GHG sink – while reducing deforestation and freshwater use by 55 per cent and 35 per cent respectively.
- *Agroecological food production has the potential to be a net job creator,* and tends to employ more people per unit of agricultural production than conventional agriculture. Additionally, facilities for ensuring food safety and higher quality of food processing in rural areas could create new, high-quality jobs in the food production chain. The two scenarios (G1 and G2) conceived by the Millennium Institute suggest that investments in ecological agriculture could create 12 million and 66 million additional jobs, respectively, compared with the BAU scenario over the next 40 years.
- *A transition to agroecological farming practices will require additional investments.* The aggregate global cost of the investments and policy interventions required for a transition towards green agriculture is estimated to average between $83 and $141 billion per annum over the period 2011 to 2050 for the 1 or 2 per cent GDP scenarios, respectively, and it will provide significant ancillary benefits to other economic sectors and the environment. It should be noted that compared with the present level of (perverse) subsidies to industrial agriculture of more than $300 billion per annum, the investment

suggested by the *Stern Review* is very modest – too modest in fact to achieve the needed levels of GHG mitigation and realize the full potential of environmental services.

Sustainable agriculture requires investments in research and capacity-building in the following key areas: soil fertility management, more efficient and sustainable water use, crop and livestock diversification, and plant and animal health management, as well as pre- and post-harvest loss reduction. It also requires substantial investments in appropriate levels of mechanization, building upstream and downstream supply chains for businesses and trade, reduction of food processing waste, supporting and implementing capacity-building efforts, such as farmer field schools (including expanding and equipping agricultural extension services with modern ICT tools), and facilitating improved market access for smallholder farmers and cooperatives.

Not unlike agricultural modernization, sustainable agriculture requires institutional strengthening, including reform of land rights, good governance and infrastructure development, such as roads, electrification and internet access in rural areas in developing countries (IAASTD, 2009). These can be summed up as enabling conditions.

- *Sustainable agriculture also requires national and international policy innovations, including in international trade policy.* Such policy changes should focus particularly on reforming "environmentally harmful" subsidies that artificially lower costs of agricultural inputs and promote their excessive use. Policy measures are needed that reward farmers for positive externalities such as reducing fossil-fuel-based agricultural inputs and implementing other sustainable/green agricultural practices. Changes in trade policies that increase access of agricultural exports originating in developing countries to markets in high-income countries are also necessary, along with reforms of trade-distorting production and export subsidies. These will facilitate greater participation by smallholder farmers, cooperatives and local food-processing enterprises in food production value chains. Governments will also need to consider supporting their farmers by means of prize stabilization funds. In addition, they should consider setting up strategic reserves to cope with unexpected events, and, more and more likely, extreme weather events such as droughts, floods and storms resulting from climate change (for a more detailed discussion, see chapter 5 of this Review).

Commentary I: Effective Extension Services for Systemic Change: Achievements and Barriers to Implementation

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Abstract

The role of extension services has widened beyond simply dissemination of information, and now includes the brokering and facilitation of multi-stakeholder innovation networks. This expanded role needs to be further developed, in terms of boosting their capacities, and recognized as catalytic to systemic change.

A. Introduction

In the light of the challenges facing the current agricultural sector, innovation is crucial to achieving a systemic shift from conventional, industrial, monoculture-based production systems that are highly dependent on external inputs, towards more sustainable production systems that both improve the productivity of small-scale farmers and facilitate self-sustained local rural development. This requires system-wide adaptations in both production and consumption systems, as well as a reordering of the value chain. Many countries are attempting to reform their agricultural innovation support systems with the aim of developing flexible and responsive capacities to achieve this systemic change. Central to this reform is the shift from a linear approach to innovation, in which public sector agricultural research and extension delivers new technology in a pipeline configuration (i.e. through a linear flow from research, via extension, to farmers), to a systemic approach in which innovation is the result of a process of networking, interactive learning and negotiation among a heterogeneous set of public, private and civil society actors (World Bank, 2006; IAASTD, 2009). Such an approach recognizes that systemic change in agriculture beyond new technical practices requires institutional change involving alternative ways of organizing, for example markets, labour, land tenure and distribution of benefits.

This paper discusses the changing role of extension services in such an innovation system, aimed at contributing to a systemic change in agricultural production systems.

B. Changing definitions and roles of extension

In many countries, advice to farmers is provided not just by a single public extension service, but rather by several extension services (also increasingly called "advisory services") which consist of a plethora of public, private and NGO-based advisers (Rivera and Sulaiman, 2009). This implies that extension systems today can be very broadly defined as "systems that should facilitate the access of farmers, their organizations and other market actors to knowledge, information and technologies; facilitate their interaction with partners in research, education, agri-business, and other relevant institutions; and assist them to develop their own technical, organizational and management skills and practices" (Christoplos, 2010: 3). The role of extension in rural areas has thus expanded to include services that go beyond agriculture, and may include the following (Christoplos, 2010):

- Dissemination of information about technologies, new research, markets, input and financial services, as well as climate and weather.
- Training and advice for individual farmers, groups of farmers, farmer organizations, cooperatives and other agribusinesses along the market chain.
- Testing and practical adaptation of new on-farm technologies and practices.
- Development of business management skills among smallholder farmers and other local entrepreneurs.
- Facilitating linkages among market actors (e.g. for financial and non-financial inputs, processing

Box 1: Brokering the South-American Papa Andina sustainable value chain innovation network

The International Potato Centre (CIP) in Peru serves as an innovation broker through the Papa Andina network in the context of value chain innovations (which link farmers to markets) in Bolivia, Ecuador and Peru (for details, see Devaux et al., 2009 and 2010). By applying a so-called participatory market chain approach, relevant market chain actors are brought together to discuss possible innovations, and trust has been built amongst organizations as diverse as agricultural research organizations, NGOs, farmer groups and traders, which in the past had not generally interacted. These actors are brought together on stakeholder platforms, both at the local level amongst potato providers, local authorities and a range of service providers (e.g. inputs), and also at the market chain level, including traders, processors, supermarkets, researchers and extension agents. As a result, new products have been created with greater value added for small farmers. For example, potato chips made from indigenous potato varieties produced by smallholders are marketed in Peru under the Lay's label which is owned by the multinational corporation, Pepsico (Thiele et al., 2009).

and trading), including brokering collaboration and promoting learning among them.

- Linking smallholder farmers, rural entrepreneurs and other members of the agricultural community with institutions that offer training and education in fields relevant to the agricultural sector.
- Facilitating linkages between farmers, their organizations and the public sector.
- Supporting institutional development processes and social, institutional and organizational innovations.
- Supporting the development of informal and formal farmer organizations, and rural youth organizations, and helping them to articulate their demands.
- Support for implementing government policies and programmes through information, awareness and advice on technological options, including land stewardship, food safety and animal welfare.
- Contributing to the development of more appropriate policies and programmes by facilitating feedback from farmers and local entrepreneurs.
- Increasing awareness of new opportunities for certification of ''green,'' fair trade and other production methods.
- Facilitating access to non-extension government support (such as weather-related insurance, phytosanitary and certification services) and subsidy programmes, including payment to farmers for environmental services and other schemes related to carbon credits.
- Facilitating access to credit from rural finance institutions for farmers and local entrepreneurs.
- Providing nutrition education.
- Mediating in conflicts over natural resources.
- Providing legal and fiscal advice.

C. The role of extension as systemic "innovation brokers"

The above description of the expanded role of extension services makes it clear that to enhance multi-stakeholder interaction for systemic change, extension services need to provide more than only one-on-one technical advice and training (although this remains an important and essential function of extension); they also need to serve as *innovation brokers* in innovation systems (Klerkx, Hall and Leeuwis, 2009), enhancing the formation of multi-stakeholder learning and innovation networks and acting as facilitators of those networks. Such innovation brokers perform three core functions:

- Articulating demand: articulating innovation needs and visions as well as corresponding demands in terms of technology, knowledge, funding and policy, achieved through problem diagnosis and foresight exercises.
- Supporting the creation of networks: facilitating linkages amongst relevant actors (i.e. scanning, scoping, filtering and matchmaking of possible cooperation partners).
- Undertaking innovation process management: enhancing convergence of goals and interests and mutual understanding in multi-stakeholder networks comprising actors with different institutional reference frames related to norms, values, and incentive and reward systems.

There are several examples of the usefulness of this innovation broker role in developing countries for achieving the needed (simultaneous) adaptations at several levels in production systems and value chains (see boxes 1 and 2).

Box 2: Innovation brokering for inclusive, demand-driven research and innovation in India: National Agricultural Innovation Programme

To make research more demand-driven and supportive of farmers' innovation processes, the National Agricultural Innovation Programme (NAIP) of the Indian Council of Agricultural Research focuses on establishing consortia of public research organizations in partnership with farmers' groups, the private sector, civil society organizations and other stakeholders around agricultural development themes. Within NAIP's layered and decentralized governance structure, the Project Implementation Unit is responsible for coordinating and facilitating implementation, while consortium implementation committees coordinate the research consortia. In other words, the NAIP aims to connect research more effectively with innovation practices. It performs this task by using technology forecasting to help develop a vision of what can be achieved, bringing actors together and organizing multi-stakeholder priority setting exercises, and operating as an agent of change in the policy and institutional environment to enable innovation. Establishing this kind of enabling environment requires changes in funding systems, incentives, skills and an organizational culture to make research more receptive to demand-driven, participatory approaches that are gender-sensitive and encompass whole sectors (farmers, other rural entrepreneurs, input supply and agri-processing industries, traders and retailers). Additional requirements are the development of business planning skills, support for incubator organizations for transforming innovative research ideas into sound commercial ventures, and the use of ICT systems to manage knowledge, enhance information-sharing and match the demand for information to its supply.

Source: www.naip.icar.org.in.

D. Innovative extension approaches at the farm level

These innovation brokers typically target a variety of stakeholders for achieving systemic change, and often act at regional, national and sectoral levels. They may also target relatively small groups of more innovative and entrepreneurial farmers. In addition, innovative extension modalities and methods have been developed to support systemic change at the farm level and the scaling up of innovations that facilitate such change. Three promising approaches are farmer field schools (FFS), the use of video-mediated learning, and the use of information and communication technologies (ICTs) and mobile phones.

FFS are a participatory method of sustainable technology development based on adult education principles, such as experiential learning (Davis, 2008) and a form of farmer-to-farmer extension. Groups of farmers meet in an informal setting on their farms with a facilitator, such as an extension worker. The FFS is an interactive training method to enable farmers to become technical experts on their farming systems, and farmers are helped to diagnose problems, find solutions, conduct experiments and disseminate what they have learned to other farmers.

Participatory or farmer-led video presentations are a powerful tool that can significantly increase the impact of good practices and research (Van Mele, 2008; Van Mele, Wanvoeke and Zossou, 2010). They offer the advantage of being more cost-effective than farmer-to-farmer extension, and can sometimes have a stronger learning impact, because they offer a better means of explaining underlying biological or physical processes. Furthermore, farmer-led videos can valorize and build on farmers' knowledge and explain innovation in their own language. The Africa Rice Center in Côte d'Ivoire has facilitated the development and translation of 11 rice videos (Van Mele, Wanvoeke and Zossou, 2010) which have been translated into 30 African languages. Open air video shows have enhanced learning, experimentation, confidence, trust and group cohesion among rural people. The farmer-led learning videos (i) enable unsupervised learning, (ii) foster local creativity and experimentation, (iii) facilitate institutional innovations, and (iv) improve social inclusion of the poor, the youth and women.

Following the rapid spread of the Internet and mobile phones in many developing countries, a range of ICTs (such as information kiosks and telecentres) and mobile-phone-based "infomediaries" have emerged (Ballantyne, 2009), which enable smallholder farmers to access, for example, relevant sources of market information, input prices and animal health information. An example of positive change in animal health care systems is FARM-Africa, an NGO working in Kenya which developed a decentralized animal health-care system in its Kenya Dairy Goat and Capacity Building Project (KDGCBP) (Kithuka, Mutemi and Mohamed, 2007). The KDGCBP system works with community animal health workers, who buy drug kits and mobile phones at a subsidized price. The project also installs community phones at veterinary shops, powered by solar panels and batteries in villages that lack electricity. The phone system allows animal health workers to share information and updates and conduct referrals, and it results in lower transaction costs, which enhances the efficiency of animal health-care provision.

E. Barriers to implementation of effective extension services for systemic change

Implementation of an innovation broker role for extension services and the use of extension methods such as FFS and participatory videos, while key to achieving systemic change, are not without challenges and barriers. These relate to capacity and funding.

- *Capacity*: while extension services are urged to develop into facilitating organizations that connect farmers with different sets of service providers, many still adhere to a linear transfer-of-technology paradigm (Rivera and Sulaiman, 2009). Extension organizations either do not see the innovation broker role as central to their core business, or they do not give the freedom to execute the innovation broker role within their mandate. Thus there are still constraints in terms of mind-set and capacity, which need to be overcome by (re-)training extension providers and retooling or reinventing extension in order to play the role of innovation broker. However, this will not be an easy process.
- *Funding*: funding agencies such as donors and governments should recognize the importance of the brokering and facilitating role of extension. These are typically activities with “soft impacts” which are not easy to capture in the hard indicators needed to show effectiveness, and hence there may be a reluctance to fund such activities (Klerkx, Hall and Leeuwis, 2009). Developing adequate measurements of the “intangibles” that matter for stimulating innovation and systemic change is therefore a major concern (GFRAS, 2011). It is worth noting that recent studies (e.g. Davis et al., 2012; Friiss-Hansen and Duveskog, 2012; Yorobe Jr., Rejesus and Hammig, 2011) have found positive impacts of methods such as FFS.

Commentary II: Combining Indigenous African Knowledge with Modern Knowledge Systems for Food Security in Changing Climatic Conditions: Challenges and Prospects

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Abstract

Improving the use of indigenous knowledge systems (IKS) through their effective combination with modern knowledge and technology systems is an important issue, in particular for Africa. Modern technology systems often tend to marginalize African IKS and are thus not sustainable. Any interface between the two will only be relevant if indigenous agricultural practices are applied to agriculture in Africa in a way that enables African farmers to become knowledge creators and recognizes IKS as an important source of knowledge. To enable the exchange of information between the two knowledge systems, participatory measures should be taken to capture and conserve African IKS and disseminate it among agricultural researchers and extension workers, ensuring that both systems of knowledge are relevant in local settings.

A. Introduction

African communities living in different ecological conditions have developed their own local or indigenous knowledge and technological systems over the years to ensure food security in changing climatic conditions (Kazinga, 2002). Werner (2000) defines indigenous knowledge systems as bodies of knowledge, skills and beliefs generated locally, and traditionally transmitted orally from one generation to the other. WHO (2001) has defined food security as existing when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life. Sefa (2004) states that, for their survival, more than 60 per cent of the people in Africa, especially in the rural areas, depend on IKS for food security, health, natural resource management, conflict resolution and natural disaster management, including adaptation to and mitigation of the effects of climate change such as drought and floods. These local knowledge systems are affordable, culturally acceptable and hence sustainable. Through an examination of secondary sources, this paper provides examples of IKS in agriculture, and discusses the prospects and challenges of interfacing IKS with modern knowledge and technological systems to enhance food security in changing climatic conditions.

B. Indigenous African agricultural knowledge and technological systems for food security

Archaeological findings in various parts of Africa show that agriculture started several millennia before the Christian era. It has been found that the growing of domestic wheat/barley in the western desert of Egypt dates as far back as around 7,000 B.C., and there is evidence of animal husbandry (sheep/goats) dating back to around 6,000 B.C. African food technologies have not only withstood the test of time but have also spread across the globe, adapting to and mitigating climate change (Sefa, 2004). Some of the indigenous African agricultural knowledge and technological systems are enumerated and discussed below.

(i) Mixed or multiple cropping. This is the growing of two or more crops simultaneously on the same piece of land. The concept behind this system is that planting multiple crops has various advantages for household and community food security, including preventing the loss of soil nutrients, reducing weeds and insect pests, increasing resistance to climate extremes (wet, dry, hot, cold), reducing plant diseases, increasing overall productivity and using scarce resources to the fullest extent. It also provides insurance against crop failure due to abnormal weather conditions. There are different variants of intercropping systems practiced in Africa. These include mixed intercropping, row intercropping and relay intercropping. Mixed intercropping, whereby the component crops are totally mixed in the field, is the basic form used in most African countries. An example of a common practice in the coastal areas of East Africa (Kenya and the United Republic of Tanzania) is mixed growing of perennials such as cashews, coconuts and mangoes. Other combinations include cassava mixed with bananas, maize mixed with legumes, sorghum with pigeon peas, and cotton with cowpeas.

(ii) Shifting/rotational farming. Zarb (2011) defines rotational farming as the cultural and physical integration of forest and agriculture, which stresses the connection between the agricultural system and the ecosystem. When the fields are fallow, they allow the regeneration of the soil and land, and this is followed by another cycle of farming. The fallow period promotes rich nutrients to create a continuing system of agriculture. The cycle aids the regeneration of fauna and flora thereby conserving local biodiversity. Samuel (2000) elaborates the advantages of this system based on his experiences in the Congo and Cameroon. The local communities there were able to cultivate a wide variety of plant species due to a 6- to 10-year period of fallow. According to his observation, the rotational farming system as an indigenous food security strategy, was not a stand-alone system, but was combined with other systems such as kitchen gardens, animal husbandry, hunting and gathering.

However, the current discourse on the challenges of climate change has created prejudice against rotational farming (CARE, 2004). People tend to blame deforestation, forest fires and slash-and-burn practices as some of the causes of carbon emissions. This criticism is refuted by Anderson (2007) using his observations of rotational farming in eastern Nigeria. He indicates that the fallow system offers opportunities for adaptation of farming to climate change. According to his study, the shifting cultivators nurture the forests even during the cultivation phase. If fallow periods are long enough, rotational farming is a stable system that maintains soil fertility, and can therefore be expected to be carbon neutral. The biomass accumulation in rotational farming is lowest after two cycles (each lasting at least six years), highest after one or four cycles, and intermediate after six to ten cycles.

(iii) Selection of specific crops and agricultural practices suited to particular climatic and ecological conditions. In arid and semi-arid areas, nomadic pastoralists practice extensive grazing, and cultivators grow drought resistant crops such as millet and sorghum, short-cycle cowpeas, phaseolus beans and groundnuts (Carpenter, 2006). In humid and sub-humid conditions, farmers grow food crops such as millet, sorghum, maize, groundnuts, cassava, cowpeas, sweet potatoes, rain-fed rice, soybeans, bananas and yams.

(iv) The importance of indigenous African post-harvest technologies for the preservation of perishable food crops, such as root crops (e.g. cassava, yams and sweet potatoes) grown mainly in the humid and sub-humid tropics, cannot be overemphasized, given that much of the food harvest produced in African countries is lost to spoilage and infestations (Kawesa, 2001). Traditional African societies that have been largely dependent on these staples have developed various local storage and processing techniques for them over the years. According to Kawesa, the cultural-historical evolution of these societies in relation to their food plants has, in general, made them strongly eco-centric in their thinking, in contrast to the techno-centric approach prevailing in the Western world. The different staples are adapted to particular ecosystems and the crops harvested need different approaches in the post-harvest technologies. For instance, cassava has highly perishable roots that can be stored for only a few days. To overcome this constraint, some African societies have developed indigenous techniques (that have been substantially improved by recent research) for storing the roots for substantial periods (Bakr, 2000). Most cassava-consuming cultures also process the roots using a variety of soaking, drying or fermentation techniques to produce stable dried products in which the level of the toxic, cyanide, is substantially reduced.

(v) Rearing of drought-resistant animals such as goats, sheep and cows. Phephe (2000) discusses the advantages of keeping savannah goats in the arid and semi-arid climate of Southern Africa. They are hardy and adaptable, with a natural resistance to tick-borne diseases, such as heartwater, and other external parasites, and require minimum handling and care. They are also heat- and drought-resistant, and easily endure cold and rain, while their pigmented skin provides protection from strong ultraviolet rays. They have relatively simple and low nutritional requirements, and can survive and reproduce where other small stock breeds cannot exist. The savannah goats fetch a higher net profit because of lower input costs. They breed year round, exhibit early sexual maturity and have long reproductive lives. In addition, range performance trials have shown that they are resistant to mouth and hoof problems.

(vi) African indigenous communities have rich knowledge of natural disaster management, as illustrated by Pitso (2008). For example, the Batswana, Zulu and other ethnic groups in Southern Africa have used the behaviour of various animals, birds, plants and insects as early warning indicators of natural disasters such as drought, floods and famine.

(vii) In her study of indigenous food security systems in eastern Zambia, Matike (2008) looks at the role played by traditional granaries as a post-harvest strategy to ensure food security. The traditional granary is the poor man's food store, built using local materials, knowledge and skills to store and preserve seeds and food crops, such as maize, millet and sorghum, dried beans and cassava, for future use and planting. The granaries are built on elevations to protect the grains from moisture, insects and rodents.

(viii) Traditional governance has played an important role in food security, according to a study by Disatsagae (2007). For example, the study observed that among the Zulu and Xhosa people in South Africa, local chiefs maintained community granaries to protect their people from starvation during natural disasters such as famines, floods and drought.

(ix) Observing nature to predict weather. Nganyi rainmakers in the Luhya community of western Kenya have been predicting the weather for generations, using changes in nature to guide their advice on how the community should time its farming (Ogallo, 2010). However, the erratic weather patterns caused by climate change mean that these rainmakers can no longer use natural signs, such as observing when trees shed their leaves or the behaviour of ants, to make their predictions. Moreover, they do not have access to the technologies available to meteorologists. A joint project by the United Kingdom and Canada links the rainmakers with government meteorologists. The two groups get together each season and produce a forecast which is disseminated using a variety of methods suited to communities where many people are illiterate.

C. Combining indigenous African knowledge with modern knowledge and technologies: Prospects and challenges

With over 40,000 plant species and over 1,000 ethnic groups, Africa has both the cultural and indigenous plant diversity needed to invigorate its agricultural economy and ensure its food security under changing climatic conditions (UNDP, 1999). People in the region use close to 4,000 indigenous plants for food, including fruit, cereals, legumes, leafy vegetables (about 1,000 different kinds), tubers and roots, and many non-foods such as gums and additives. The high cultural diversity is linked to versatile indigenous knowledge and related practices, including a variety of food processing techniques and recipes. However, in spite of this great potential, indigenous knowledge has not been effectively used to reduce current widespread malnutrition and poverty. The types of indigenous foods consumed by most African communities, especially in the rural areas, and the methods of handling, processing, marketing, distribution and utilization are deeply rooted in tradition and experience, leading to the development of various indigenous food technologies. These technologies are based on local knowledge, experience, art, culture and belief systems, and have been distilled from local experiences over centuries. They affect the economic and social lives of the operators, are simple, labour-intensive, and predominantly home-based and controlled by women. However, they are also time-consuming, with poor or no quality control.

Matike (2008) provides examples of best practices in combining indigenous and modern technologies in eastern Zambia, such as local farmers using modern sprayers to treat their farms with organic fertilizers and pesticides (liquid tea). In the United Republic of Tanzania and in other parts of Africa, increasingly, indigenous seasonal foods are being stored in modern food storage and preservation facilities, including driers and fridges, to prolong their shelf life (Kawesa, 2001). However, Kawesa argues that while the interface between African indigenous knowledge and modern knowledge systems is important to enhance food security and promote climate change adaptation and mitigation, in the context of African indigenous knowledge systems, food production and consumption are much more than just economic or nutritional activities. The processes and practices involved take place within specific social, cultural and political contexts which are not always understood by scholars, researchers and policymakers trained in Western environments and perspectives. This has led to the failure of many development projects that aimed to improve the efficiency of African indigenous food technologies. For example, the Green Revolution demonstrated the consequences of “outsider” knowledge: it generally succeeded in places where the technology was developed, and failed in those places where local farmers’ needs, values and constraints differed from those where the technology was developed (Glaeser, 1990).

Increasingly, a growing number of African scientists and policymakers are becoming aware that IKS can make a significant contribution to enhancing food security and sustainable development (Flora, 1992). Such knowledge is relevant to the modern scientific world for a number of reasons, including for the protection of biodiversity and the intellectual property of the indigenous knowledge holders. IKS could be used as the basis for the construction of a truly alternative agriculture for food security and sustainable community livelihoods in Africa, which is why it is being increasingly included in the agendas of research and development institutions. There needs to be a “deconstructive” process in the “reconstruction” of an alternative science applicable to agriculture. In order to achieve just and sustainable agriculture for food security under changing climatic conditions, it is necessary to recognize that knowledge has multiple sources, including IKS. In a study that mapped and audited indigenous agricultural knowledge in the Uasin Gishu and Keiyo districts in the Rift Valley Province (Kenya), Kiplang’ at and Rotich (2008) have suggested measures for improving the capturing, preserving and disseminating of African indigenous knowledge to agricultural researchers, extension workers and farmers. This should facilitate the exchange of information between indigenous knowledge practitioners and agricultural extension services, promote cultural acceptability of development projects and programmes, increase agricultural productivity and food security, promote local agricultural content in modern technological applications, and create community-based income-earning opportunities for local farmers.

Commentary III: The Symbiosis Between Modern Science and Traditional Knowledge for Enhancing Food Security and Climate Change Adaptation

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Abstract

This comment demonstrates the richness of indigenous knowledge (IK) and the diversity of IK-related indicators for monitoring climate variability and change. Although the indicators were not compared with seasonal forecasts issued by the respective formal institutions, it is evident that this rich knowledge is yet to be fully harnessed and combined with modern science. Knowledge-sharing among scientists and pastoralists, combined with capacity-building, is necessary for improving the quality of climate forecasts, and enabling pastoralists and extension agents to interpret the probabilistic climate information in order to generate "best bet" on-farm practices for the various seasons. This will eventually contribute to increased food and nutrition security in developing countries.

Climate change and variability are issues of great concern globally, and are more pronounced in developing countries that face many development challenges. Current reports indicate that the world's climate is changing at unprecedented rates, affecting ecosystem functions and processes, biodiversity and the human population. Therefore, there is a need to develop all-inclusive robust strategies for climate change mitigation and adaptation to the changing environmental conditions. Modern technologies have played an important role in the sustainable management of natural resources in the past, but with the likelihood of further changes occurring, modern science alone cannot conserve nature or mitigate the effects of, and facilitate adaptation to, climate change to enhance food security. To achieve this, it will be necessary to integrate traditional knowledge and institutions with modern science. This commentary provides examples from Kenya – a country in sub-Saharan Africa that has enormous biodiversity – to show the potential of traditional knowledge for promoting conservation of biological diversity and climate change mitigation. General lessons are also drawn from other areas in Africa on the use of traditional knowledge, practices and institutions in designing responses to climate change.

A. Introduction

Strategies of mitigation and adaptation to changing environmental conditions have been emphasized in numerous discussions at a number of forums, including the United Nations Framework Convention on Climate Change Conferences. For the majority of communities throughout the world that directly utilize natural resources for their livelihoods, the expected changes in climate during this century present significant threats of disturbances (Thomas et al., 2007), especially where changes may be unprecedented and pervasive (Cooper et al., 2008).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) indicates that the exact nature of changes in climate remains uncertain, but the likeliest scenario is increased variability, particularly at the extremes. Therefore, approaches for mitigating the accompanying direct and collateral effects need to be discussed by indigenous communities, scientists, development partners and the political class.

There are potential synergies from combining IK with emerging and new patterns in science to produce optimum knowledge. IK usually builds on holistic pictures of the environment by considering a large number of variables qualitatively, while science tends to concentrate on a small number of variables quantitatively. Recent studies by Abedi and Badragheh (2011) indicate that IK is a valuable source of practices and a time-tested tool that would be useful to harness for sustainable development and for improving food security. It is becoming crucially important to recognize the limits of our scientific knowledge (Brown, 2004) and to review our understanding of what uncertainty and variability implies, as well as to examine how indigenous communities live their everyday lives. This commentary provides examples from Kenya and draws general lessons from other areas in Africa about the use of traditional knowledge, practices and institutions in designing responses to climate change and variability.

B. Congruence of indigenous and scientific knowledge systems in climate prediction

The role of climate and weather information in helping the farming community to make critical decisions for adaptation to climate change and variability cannot be overemphasized. Farm-based decision-making in developing countries relies to a large extent on indigenous weather forecasts, partly because of the absence of formal climate information systems in some developing countries. In other countries where meteorological services are developed, there exist several challenges in communicating this information to vulnerable communities. But overall, it has been observed that the accuracy of modern meteorological predictions and IK-based forecasts is fairly comparable (Orlove et al., 2010).

Traditionally, farmers have been using their own knowledge to predict rainfall – knowledge that has evolved through observations and experience over several decades and passed on from one generation to the other. In weather forecasting, they have been using a set of indicators and have developed a reliability factor for each of them. However, it is only when IK is used, challenged and adapted to changing contexts that it will contribute to climate change adaptation. Despite the increasing interest in the use of IK, scepticism towards it persists, which limits its spread to management practice and science (Gilchrist, Mallory and Merkel, 2005; Orlove et al., 2010).

Consequently, it is useful to document and compare these experiences across agro-ecological zones and livelihood groups with a view to drawing some lessons and recommendations on how indigenous forecasting may be strengthened to support adaptation in different settings.

C. Indigenous knowledge and drought monitoring: a case of Kenyan agro-pastoralism

Agro-pastoral production systems have been classified based on a number of criteria (Otte and Chilonda, 2003). Pastoralists and agro-pastoralists usually derive IK-based forecasts just before the beginning of the farming season. In northern Kenya, the Rendille pastoralists utilize a number of indicators from local weather, ranging from temperature, humidity and wind conditions to the presence or absence of certain types of clouds, rainfall patterns and amounts. These weather indicators are also used in formal climate monitoring.

Additionally, when predicting prolonged drought, the Rendille pastoralists observe the flora and fauna for any unusual behaviour, such as noises of certain birds, the appearance of sparrow weavers (green bird), bees migrating, livestock species looking emaciated even when there is plenty of pasture, the invasion of certain ants, the making of noise by crickets at night, and unusual flowering of certain trees (e.g. *Lonchocarpus sp. sterile*). Astrological constellations, like the position of the sun and moon are also observed in great detail by the Rendille and Gabra pastoralists. Interestingly, a number of these indicators have also been used for drought monitoring in other communities such as the Kamba agro-pastoralists of Kenya (Speranza et al., 2009).

There are, however, some dissenting opinions over the effectiveness of indicators used by the communities across countries and the world, and further studies are necessary to better capture the nature of the indicators. Luseno et al. (2003) suggest that indigenous methods for climate forecasting could offer insights to improve the value of modern seasonal forecasts for pastoralists in East Africa. They argue that indigenous forecasting methods are needs-driven, focus on the locality and timing of rains, and are "communicated in local languages and typically by experts' known and trusted by pastoralists". In contrast, in Burkina Faso (Roncoli et al., 2000) and

Lesotho (Ziervogel and Downing, 2004), there is less use of local forecasting knowledge, which is attributed to increased climate variability, leading to less consistency between indicators and outcomes due to the changing social environment. Consequently, farmers in these countries have also been showing interest in how they might be able to use seasonal meteorological forecasts to make critical farming decisions.

Developed countries have tended to reject the IK of local communities as primitive, non-quantitative, employing non-conventional methods and unscientific. However, more recently, IK systems have attracted the attention of many observers in both developed and developing countries. Practitioners are starting to realize the importance of recognizing and working with IK, which builds on generations of experience, to best support the adaptive capacity and strategies of rural communities (Speranza et al., 2009; Orlove et al., 2010).

D. Adaptation strategies

Large proportions of pastoral rangelands in arid and semi-arid lands (ASALs) have been systematically degraded over time, while absolute numbers of livestock have increased and are now threatening the health of ASAL habitat through overgrazing and, subsequently, soil erosion (Mganga et al., 2010). Consequently, most of the ASALs are currently unable to support growth of natural vegetation, besides diminishing the carbon sink. This raises doubts about the sustainability of pastoralism as a means of livelihood. In the ASALs of northern Kenya, the main factor influencing the productivity of livestock, which is the predominant economic activity, is feed availability (Peacock and Sherman, 2010). Yet there are few alternatives to livestock mobility as an efficient adaptive management strategy to overcome feed deficits.

The pastoralist groups in Kenya have developed fairly effective coping strategies in response to drought events aimed at minimizing losses or facilitating recovery after drought. The practice of keeping mixed herds of grazers and browsers not only ensures that the animals make use of the different resources (e.g. grasses and shrubs), but it is also a risk management strategy, as the different groups of animals are unlikely to be affected in the same way during periods of drought. Additionally, many households keep animals elsewhere, with relatives and friends, to guard against losses through disease, raids or drought. Such animals always come in handy after a disaster, as the pastoralist families are able to restock quickly and carry on with their lives. Communal ownership and management of natural resources are central to pastoralism in northern Kenya because they ensure that livestock keepers move freely as they search for water and pastures in different locations at different times of the year.

Nyong, Adesina and Osman Elasha (2007) observed that the people of the African Sahel practice zero tillage, mulching, fallowing, agro-forestry and organic farming – practices that create carbon sinks. They report that IK has been used in weather forecasting and vulnerability assessment, and for implementation of adaptation strategies such as conservation of biodiversity, use of emergency fodder in times of drought, multi-species composition of herds and mobility.

The unpredictable nature of rangelands forces the pastoralists to embark on strategies to take advantage of the good years. For instance, they often stock more productive females in their herds to ensure that animals lost are easily replaced when climatic conditions improve (i.e. when grass and water become abundant). Also, they keep a large number of animals, which is one of the paramount aspects of pastoralism that generally is not well understood and that often leads outsiders to call for de-stocking to levels in line with carrying capacity.

Outside observers also tend to overlook the fact that the way animals are grazed may be more important than the numbers, considering the mobile nature of pastoralists. Unfortunately, many of these strategies that have served drought-affected communities well in the past may become inadequate in the light of the more frequent occurrence of droughts and unprecedented weather extremes in recent years.

With dwindling natural resources, especially pasture and water, there is little the pastoralists can do to access such resources. It is important that external players work with these pastoralists to identify ways of creating access to those resources. For instance, farmers could be encouraged to plant pastures that can be sold to pastoralists at subsidized rates so that the pastoralists would not have to graze their animals in cultivated zones, which often gives rise to conflicts with crop farmers at present.

Commentary IV: Addressing the Causes of Land Degradation, Food and Nutritional Insecurity and Poverty: A New Approach to Agricultural Intensification in the Tropics and Subtropics

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Abstract

The shortage of new land for agriculture and the poverty of smallholder farmers in the tropics are serious constraints on the expansion of modern intensive agriculture to overcome the food crisis. Consequently, there is an urgent need for both the rehabilitation of degraded farmland and for the realization of new income-generating opportunities.

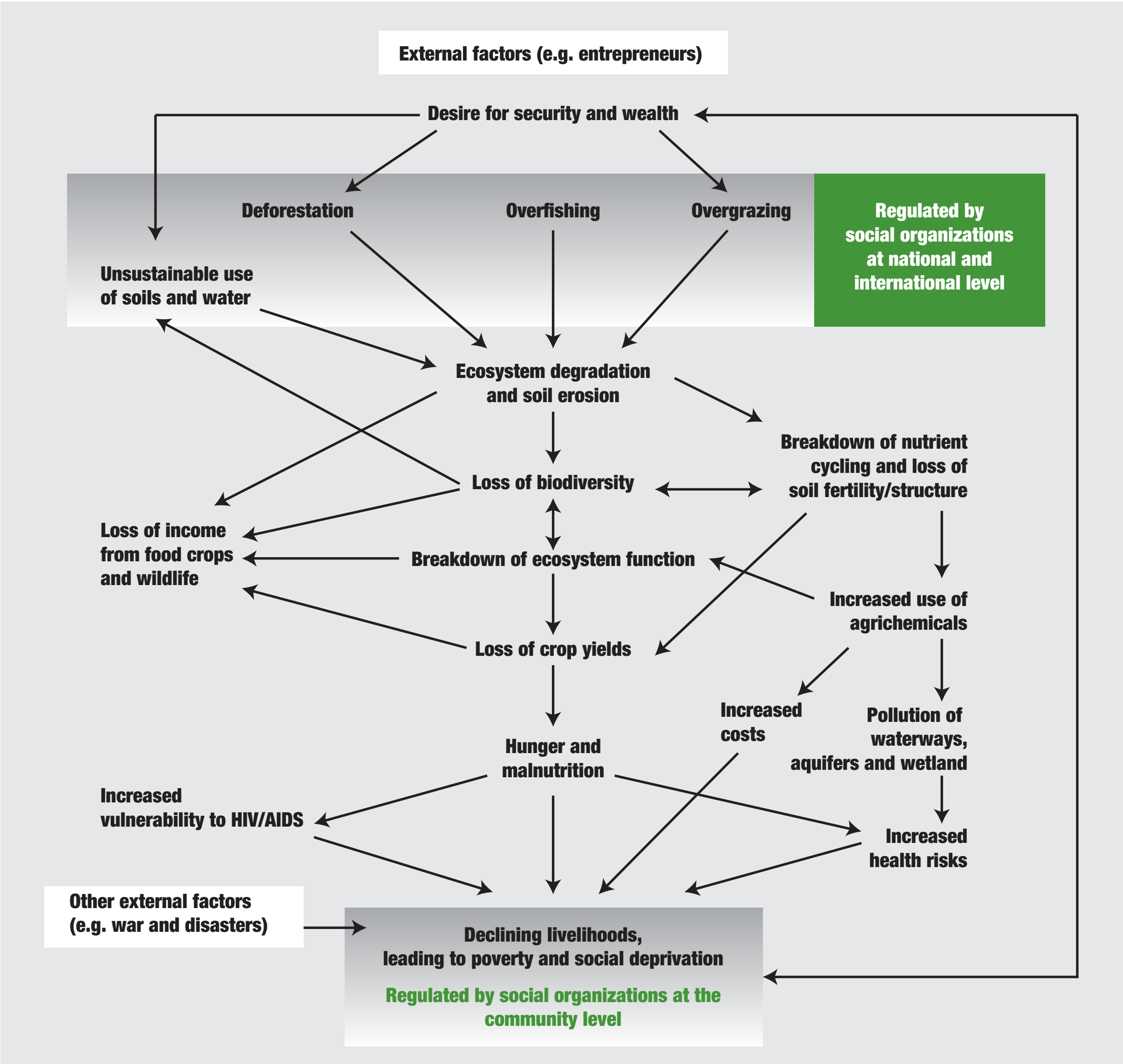
This commentary presents a tried and tested award-winning (Equator Prize) three-point action plan using biological nitrogen fixation and a "new wave" of crop domestication focusing on marketable and highly nutritious traditional foods. If widely adopted, this package could fill the yield gap of crops such as maize, thereby promoting new livestock enterprises and satisfying global food demand to 2050. It could also create new business and employment opportunities in diversified local rural economies and perhaps help expand agribusinesses.

The Green Revolution enabled a considerable increase in the productivity of conventional high-input agriculture, thereby saving millions of people from starvation. However, this achievement came at a high cost to the environment as a result of land conversion through deforestation, land degradation and the overexploitation of natural resources, especially soil and water. Moreover, such high-input agriculture is now also recognized as being a major contributor to climate change. Furthermore, despite the improved productivity of major food staples, there are still billions of people suffering from poverty, malnutrition and hunger. Consequently, there have been many calls for a new approach to food production, especially in the tropics and subtropics where the problems and issues are the most urgent and prevalent. The key issues to be addressed are land rehabilitation, food and nutritional security, and income generation – all within sustainable land-use practices. The overriding questions are: How can the land be used to feed a growing population without further damage to the local and global environment? How can food and nutritional security be achieved on a declining area of available land? And how can the land be used to enhance the livelihoods and incomes of the rural poor?

Answers to these questions fall into two main camps: there are some who believe that the only way forward is by intensifying the high-energy-input Green Revolution model involving further productivity improvements through research and breakthroughs in crop and livestock genetics; others think that more ecologically based approaches involving low-input agriculture are the way forward. To consider the merits of these two contrasting and highly polarized views, we look at the environmental and socio-economic problems arising from land conversion to agriculture, and offer some solutions.

Current land-use practices in the tropics have led to deforestation, overgrazing and overexploitation of soils and water resources (figure 1), causing a cascade of negative impacts: land degradation, loss of soil fertility, loss of biodiversity, the breakdown of agro-ecosystem functions, declining yields, hunger and malnutrition, and declining livelihoods. Associated with these are reduced access to traditional wild foods, loss of income and the increased need for costly (often unaffordable) agricultural inputs. The response of proponents of intensive, high-input industrial farming is to redouble efforts to increase the yield of staple food crops by enhancing their capacity to

Figure 1. The cycle of land degradation and social deprivation

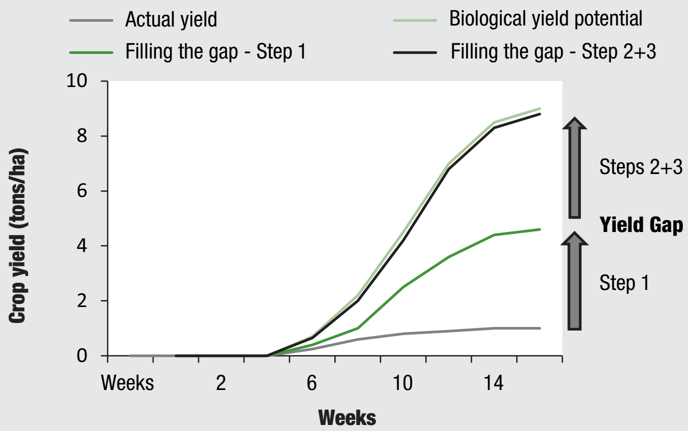


Source: Adapted from Leakey et al., 2005.

withstand biotic and abiotic stress. This approach fails to recognize three important points: (i) since farmers are failing to grow staple foods anywhere near their existing biological potential, resulting in what is called the "yield gap" – the difference between potential yield per hectare and actual yield achieved by farmers (figure 2), increasing the biological potential will not help; (ii) poor, smallholder farmers locked in a poverty trap cannot afford to buy the requisite fertilizers and pesticides (even if they had adequate access to them) that would allow them to practice monoculture agriculture; and (iii) the overriding dominance of starchy food staples in modern agriculture may provide adequate calories for survival, but they lack the proteins and micronutrients necessary for healthy living, not to mention the sensory pleasures provided by traditional and highly nutritious foods which used to be gathered from the forest. In addition, the widespread clearance of forests from the landscape, especially from hillsides, exposes soils to erosion and increases run-off, resulting in landslides and flooding that destroy property and lead to the death of large numbers of people. Loss of perennial vegetation also contributes to climate change.

Therefore, an alternative approach to agricultural intensification is required. Indeed, several recent

Figure 2. A representation of the yield gap in agriculture, and the steps needed to close the gap

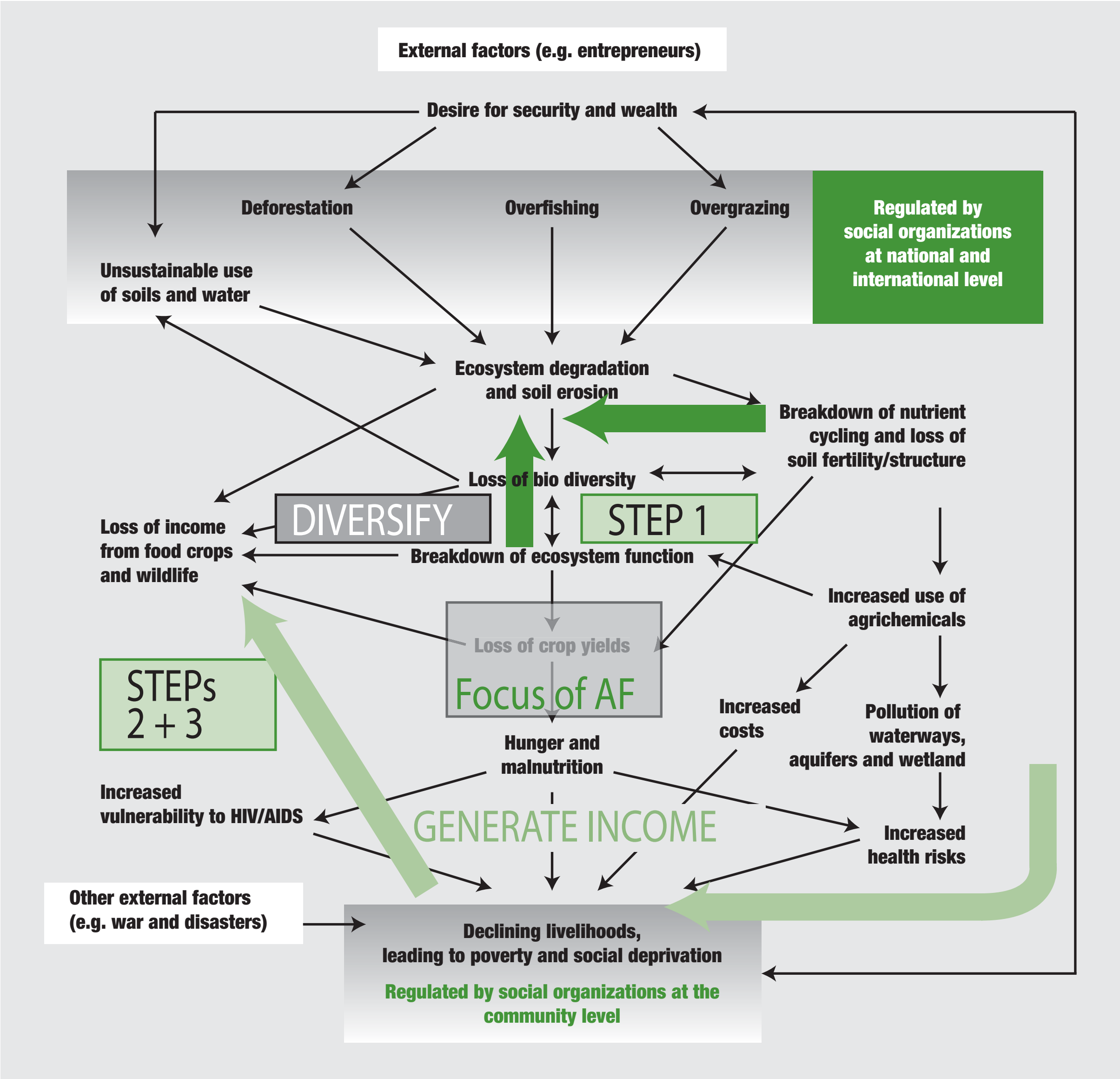


reviews of agriculture (IAASTD, 2009; Royal Society, 2009) and of issues relating to the role of agriculture in the global environment (e.g. Hassan, Scholes and Ash, 2005; UNEP, 2007; CAWMA, 2007) have suggested that "business as usual" is no longer the appropriate option due to the scale of the problems and the constraints facing poor farmers. We need to go back to basics and look at the cycle of land degradation and social deprivation (figure 1). Clearly, a focus on crop yield is important, but, rather than trying to increase yield potential, we need to focus on closing the yield gap. In the worst cases, farmers growing maize are achieving only 0.5–1 ton per hectare when the potential is around 10 tons per hectare. In this situation, closing the gap could increase food production by 15- to 20-fold; but even if it were increased by only 2- to 3-fold, on average, this would be well over the 70 per cent increase that might be required to feed the 9 billion people predicted to populate the world by 2050, according to IFPRI (2011).

The primary cause of the yield gap is poor crop husbandry, which has a number of adverse effects, including loss of soil fertility and agroecosystem functions (such as the cycling of nutrients, carbon and water), impeding the operation of life cycles and food webs that maintain the natural balance between organisms, and reducing pollination and seed dispersal. Typically, reduced soil nitrogen is the major constraint on crop growth in degraded soils. This can be restored by harnessing the capacity of certain legumes to fix atmospheric nitrogen in root nodules colonized by symbiotic bacteria (*Rhizobium* spp.). Numerous techniques have been developed to integrate appropriate legume species within farming systems. Probably the most effective and easiest to adopt are high-density improved fallows with species such as *Sesbania sesban* and *Tephrosia vogelii* or relay cropping with *Gliricidia sepium* (Cooper et al., 1996; Buresh and Cooper, 1999). Cultivating leguminous crops such as beans and peanuts can also contribute to this process. Together the legumes can increase soil nitrogen to a level that will produce maize yields of 4–5 tons per hectare within 2–3 years. This would help narrow the yield gap and greatly increase food security. However, it would not address the problem of the low levels of other soil nutrients, which means that the complete closure of the yield gap would require another approach involving the provision of inorganic nutrients, such as rock phosphate or chemical fertilizers, which have to be purchased. This necessitates income generation.

However, before addressing the need for income, it is necessary to find ways of restoring agroecosystem function. The legumes will start this process. For example, one of the more damaging weeds of cereal crops such as maize, millet and sorghum is *Striga hermonthica*. It is a root parasite on these cereals and its seeds germinate in response to root exudates from the young cereal plants. Interestingly, however, since *Sesbania sesban* and the fodder legumes *Desmonium intortum* and *D. uncinatum* also trigger *Striga* germination, they can be used to promote suicide germination in the absence of the cereal hosts (Khan et al., 2002). *Desmodium* spp. also acts as a repellent to insect pests of cereals, such as the stem borers *Busseola fusca* and *Chilo partellus*. Likewise,

Figure 3. Procedures for closing the yield gap



simple agroecological benefits can be attained by planting Napier grass (*Pennisetum purpureum*) as an intercrop or around small fields, as they attract the pests away from the crops (Khan et al., 2006).

The two interventions described above can therefore be used to restore soil fertility and initiate an agroecological succession, thereby rehabilitating farmland and reversing some of the land degradation processes. This may be considered as the first step towards closing the yield gap (figure 3).

The next step to a fully functional and more productive agroecosystem involves the integration of trees within the farming systems. Some trees are of course cash crops such as coffee, cocoa and rubber, which in the past were either grown as large-scale monocultural plantations or as a two species mix, such as cocoa under the shade of coconuts or *Gliricidium sepium*. Increasingly, however, they are becoming smallholder crops grown in much more diverse species mixing, such as bananas with fruits trees like mango, avocado and local indigenous trees that produce marketable products (Leakey and Tchoundjeu, 2001). This practice is well developed in Latin America and Asia, and is becoming widely recognized as a way to restore the biodiversity normally found in natural forests (Schroth et al., 2004; Clough et al., 2011). Certainly, the replacement of shade trees with trees

Intensive rice cultivation in the valley bottom, with hillsides planted with diverse commercially important trees for income generation and environmental benefits. Indonesia alone has about three million hectares of these "agroforests".

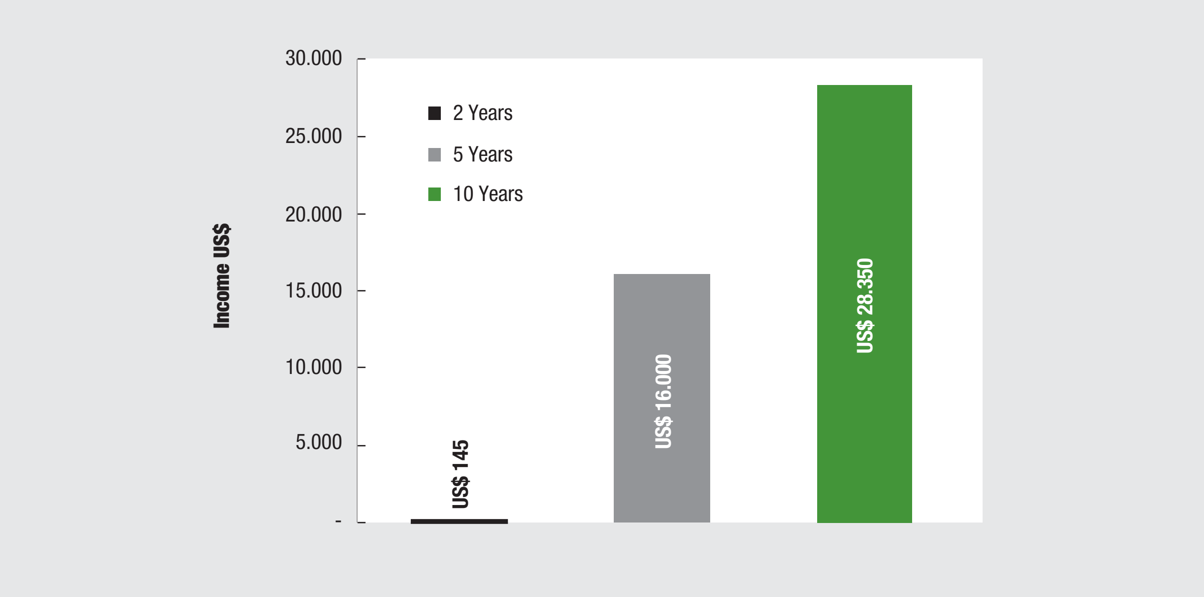
that also produce useful and marketable products is a good strategy for farmers to enable them to maximize output from the land and minimize the risks associated with excessive reliance on a single crop species.

There has also been another silent farmer-led revolution in the tropics, especially in South-East Asia. In Indonesia, in particular, many farmers who used to practice shifting agriculture have replaced the natural fallow with a commercial fallow (agroforest) based on tree crops. They grow rice in the valley floors and plant a wide range of useful and commercially important tree species among the other food crops which they have planted on the valley slopes (Michon and de Foresta, 1999). These trees become productive successively in later years, creating a continuous supply of marketable produce (e.g. cinnamon, tung nut, damar, duku and rubber) for several decades, often ending in a timber crop. This diversification of the farming system with perennial crops therefore achieves several important outcomes. It protects sloping land from erosion, improves water infiltration into the soil, sequesters carbon and so mitigates climate change, generates income, enhances biodiversity and promotes agroecosystem functions. In other words, it performs all the functions that large-scale monocultures fail to do, and the livelihoods of the farmers are far better than those locked in poverty due to growing a failed maize crop in Africa, for instance. This approach to agriculture achieves high crop yields that are close to the biological potential of the best and most fertile land, and it generates income from tree crops on the more marginal land, creating a land-use mosaic with many environmentally beneficial impacts (photograph from Vietnam). Importantly, there is also some evidence that complex perennial vegetation, such as a natural forest or an agroforest, is better than a herbaceous crop at recycling moisture to the atmosphere that can be advected downwind to fall as rain. Thus agroforests are likely to be beneficial to rain-fed agriculture in dry and drought prone areas of the world.

In a further initiative, over the past 20 years agro-foresters have sought to take this strategy to a higher level by starting to domesticate some of the very wide range of tree species which have been the source of locally important food and non-food products traditionally gathered from the forest (Leakey et al., 2005; Leakey, et al., 2012). The approach has been to apply well-known horticultural techniques of vegetative propagation for cultivar development (Leakey, 2004; Leakey and Akinnifesi, 2008). Unconventionally, this has been implemented at the village level as a

A multifunctional agriculture landscape in Viet Nam with many income-generating tree-based production systems on hillsides surrounding an area of intensive food production on the most fertile soils.

Figure 4. Income generated from tree sales by village nurseries associated with rural resources centres in north and north-west regions of Cameroon after 2, 5 and 10 years (dollars)



Source: Based on Asaah et al., 2011.

participatory process with local communities, rather than on a research station (Leakey, Schreckenberg and Tchoundjeu, 2003; Tchoundjeu et al., 2006; Asaah et al., 2011). This participatory approach has been implemented to ensure that the farmers are the instant beneficiaries of the domestication, and that they are empowered by the development of their indigenous and local knowledge. Because wild populations of tree species contain 3- to 10-fold variations of almost any trait of commercial interest (Leakey et al., 2005), there is considerable potential for substantial improvements in characteristics such as fruit/nut size, quality and chemical content. This means that new, highly productive cultivars yielding good quality produce and the product uniformity required by markets are easily obtainable. Furthermore, because the multiplication process is implemented by vegetative propagation based on mature tissues with the capacity to flower and fruit, the long unproductive period usually associated with tree crops is circumvented, and trees become productive in 2–3 years.

Proof of concept has recently been demonstrated by the implementation of a participatory tree domestication project in Cameroon (Tchoundjeu et al., 2006, 2010; Asaah et al., 2011). In 12 years the project grew from four villages and a small number of farmers to over 450 villages with 7,500 farmers. The flow of benefits, such as income generation, started within less than five years (figure 4), and the farmers are reporting many other ways in which the project has also improved their lives (Asaah et al., 2011). Perhaps the most significant outcome has been the fact that young men and women in these communities now see a future for themselves by remaining within the community rather than migrating to local towns. In addition, the processing and value addition of produce from domesticated trees and other crops have been found to provide off-farm employment and to stimulate local enterprise and trade.

Historically, crop domestication has been implicated in the rise of civilizations that have become settled, politically centralized, socially stratified, economically complex and technologically innovative societies (Diamond, 1997). As the first wave of crop domestication primarily benefited the industrial countries of the northern latitudes, it seems that the time is now ripe for a second wave of domestication to favour tropical and subtropical countries, which would enhance social equity and environmental rehabilitation worldwide (Leakey, 2011; Leakey and Asaah, forthcoming).

The creation of new cash crops from the domestication of traditionally important, highly nutritious and useful species may be considered the second step towards closing the yield gap, because they can generate the income needed for the purchase of fertilizers and other agricultural inputs (figure 2). The trees can be used to enrich and improve the farming systems, whether by providing shade for commodity crops, or by forming agroforests on hillsides, orchards, field and farm boundaries, fodder banks or woodlots. However, farmers have many other competing demands for their money, including for local ceremonies, health care, children's education, farm infrastructure and market transport. Consequently, the third step to closing the yield gap is to further expand the commercialization of these new tree crops, thus creating business opportunities and employment.

Most of the traditionally important products from tropical forests have been marketed locally for centuries. Over the past decade, an increasing number of these have been processed as new foods, and for use in medicinal, nutraceutical and cosmetic products, based on the fruits, nuts, gums, resins and fibres. Some of these have entered regional and international markets. However, the marketing and trade of commodities from tropical producers have often been exploitative. As a result, with the emergence of this new trade there has been a parallel initiative to ensure that the producers receive a fair price (see, for example, the Fair Trade Foundation at: www.fairtrade.org.uk). In addition, ways have been sought to develop marketing partnerships aimed at the pro-poor commercialization of the traditionally important products derived from indigenous trees (Lombard and Leakey, 2010). These partnerships work to develop the products to a marketable standard and establish strong and viable trade associations that are forward thinking and market oriented. Through these partnerships it is possible to establish long-term relationships and supply agreements which ensure that the producers remain in the value chain.

Another aspect that deserves attention is the importance of livestock in agriculture. The 2020 projections of the International Food Policy Research Institute (IFPRI) suggest that 40 per cent more grain production will be needed and that more meat will be consumed by the world's population. As mentioned earlier, grain production could be greatly increased by closing the yield gap. Recent developments have also demonstrated that fodder trees can be used to increase the productivity of cattle and goats. The integration of fodder trees and livestock into a farm is one of the elements of diversification that could be part of step 2.

Another recent development has been the establishment of public-private partnerships between multinational companies, national and international research teams and local producer communities to promote and produce new products for international trade. Examples include Daimler AG in Brazil which is manufacturing components for the motor industry based on products from agroforestry systems produced by local communities (Panik, 1998), as well as Unilever plc. that is developing a new oil crop for margarine production with communities in Ghana and the United Republic of Tanzania using kernel oil from *Allanblackia* spp. (Jamnadass et al., 2010).

All of these developments offer a new approach to agriculture delivered by agroforestry practices (Leakey, 2010), which is more sustainable – environmentally, socially and economically – than current conventional approaches. This model conforms to the concepts of multifunctional agriculture promoted by the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009) which was ratified by over 60 countries in 2009.

Commentary V: Adapting to Climate Change and Improving Household Food Security in Africa Through Agroforestry: Some Lessons From the Sahel

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Abstract

The future of farming in Africa's drylands and sub-humid regions will largely depend on the success of all stakeholders in developing agroforestry systems that are managed by farmers, produce multiple impacts and do not lead to recurrent costs for governments. As aptly put by a farmer from Tigray, "Trees are our backbone" (Waters-Bayer and Gebre-Michael, 2007).

Many small and bigger re-greening successes can be found in Africa's drylands. These can be used as starting points for scaling up. Scaling up can be achieved by building a grassroots organization, but it is vital to develop national policies and legislation concerning land and tree tenure, which would induce millions of small-scale farmers in Africa to invest in natural resources, in general, and in trees in particular. The development of agroforestry systems in Niger, for instance, took off as soon as farmers began perceiving an exclusive right to their on-farm trees. In parts of Mali the process began in 1994, after a change in the forestry law and after farmers were informed about the change.

Different forms of re-greening in Africa require a mix of investments, changes in policies and legislation, the building of social capital and of a movement in support of re-greening, as well as action-oriented research to quantify multiple impacts. This will make it possible to help farmers adapt to climate change, while improving household food security and alleviating rural poverty. However, there is still one major obstacle: very rapid population growth. For instance, the annual demographic growth rates in Niger and Mali are in the order of 3.6 per cent, which means that their populations will double in less than 20 years. Even if it were technically possible to feed a rapidly growing population, it will be hard to create better livelihood opportunities for most of the young people.

A. The macro context

Macro conditions in the Sahel and in other drylands in Africa seem challenging over the next decades. Temperatures are expected to increase and crop yields to remain stable at best, but most likely they will decline due to depletion of soil fertility levels and more erratic rainfall, while the population is set to double. The Sahel has faced similar challenges in the past and has been able to cope with such changes. At the end of the 1960s and the early 1970s, rainfall suddenly declined by about 30 per cent, causing widespread hunger and hardship. And many research reports analysing agriculture and the environment in the Sahel in the 1980s were very pessimistic (e.g. Marchal, 1985; Raynaut, 1987). They used terms such as failure and breakdown to describe trends in agriculture.

B. Developing new agroforestry parklands to intensify agriculture

Farmers and pastoralists in the Sahel needed some years to adapt to the lower rainfall. Recent studies on long-term trends in agriculture and the environment in the region show some surprising trends (Reij, Tappan and Belemvire, 2005; Botoni and Reij, 2009; Reij, Tappan and Smale, 2009). The first is that farmers in several densely populated regions of Niger have been protecting and managing on-farm natural regeneration of trees and bushes. This process, which began around 1985, has led to on-farm re-greening on about 5 million hectares – the largest scale of environmental transformation in the Sahel and possibly in Africa. This on-farm protection and management of useful trees, such as *Faidherbia albida* (a nitrogen-fixing species that improves soil

Young, high-density agroforestry parkland in the southern Zinder region (Niger). The parkland is dominated by *Faidherbia albida*.

fertility and provides fodder for livestock), *Piliostigma reticulatum* (for fodder), *Combretum glutinosum* (for firewood), *Adansonia digitata* (for leaves and fruit that provide high-quality nutrition), *Guiera senegalensis* (for fodder), has enabled the feeding of about 2.5 million people. The annual production value of the new trees is in the order of at least €200 million, all of which goes to farmers, not necessarily in the form of cash but in the form of produce.

The development of new agroforestry systems has had the following impacts:

- Trees reduce wind speed, and farmers in densely populated parts of Niger now plant crops once instead of 3 or 4 times as they did 20 years ago when the crops were covered by sand or destroyed by sand blast.
- The shade of the trees reduces temperature and hence evaporation.
- A number of woody species produce fodder.
- Other species fix nitrogen and contribute to soil fertility. For instance, depending on their age, a good stand of *Faidherbia albida* fixes up to 150 kg of nitrogen per hectare.
- Some trees produce fruit and leaves, with high vitamin content, for human consumption.
- They also contribute to biodiversity.
- Trees mitigate climate change by sequestering carbon.
- They help adapt to climate change by reducing wind speeds and temperatures.
- The trees improve household food security, because they create more complex and productive farming systems that are more resilient to drought. Even if crops fail, trees produce.
- The trees help increase aggregate agricultural production and thus contribute to reducing rural poverty.

This on-farm re-greening has occurred only in regions with high population densities and sandy soils, which is not surprising, as increasing population induces farmers to intensify agriculture. For farmers, protection and management of woody species that spontaneously regenerate on-farm is the least costly form of agricultural intensification as it does not require the procurement of external inputs; the only investment is that of their labour, while village institutions are responsible for the new tree stock (capital assets). It should be emphasized that this re-greening occurs mainly on-farm. In regions with low population densities, the vegetation continues to degrade and the remaining patches of natural vegetation tend to be encroached upon and deteriorate.

Many examples of farmer-managed re-greening can be found in other Sahel countries as well. For instance, it was recently discovered that farmers in Mali's Seno Plains protect and manage natural regeneration on about 450,000 ha,[4] where 90–95 per cent of the trees are younger than 20 years. As elsewhere, this region had a good tree cover in the 1950s and 1960s, but due to droughts in the 1970s and 1980s, much of the vegetation was destroyed for field cultivation. This led to large-scale wind and water erosion and declining crop yields. In the second half of the 1980s and the 1990s, farmers, governments and donors began to react to the crisis by supporting the planting of on-farm trees in a growing number of regions. Consequently, the number of such trees has been increasing in a number of regions, though not everywhere.

Some observers argue that this process of re-greening can be attributed to an increase in rainfall in the Sahel since the mid 1990s. However, a comparison of tree densities in southern Niger and northern Nigeria, which have similar soils and population densities, reveals that on-farm tree densities in northern Nigeria are much lower than in southern Niger despite the fact that the former has higher rainfall.[5] Rainfall is important for re-greening, but it seems that human management is a more important determining factor than rainfall.

C. Water harvesting techniques to rehabilitate degraded land

Farmers in the Sahel have not only developed new agroforestry systems; they have also used simple water harvesting techniques to rehabilitate strongly degraded land. In the early 1980s, the northern part of the central plateau of Burkina Faso was a kind of laboratory for testing different water harvesting techniques, such as improved traditional planting pits (also known as *zaï)* and contour stone bunds, which slow down rainfall runoff and induce it to infiltrate into the soil. As a result, more water becomes available for plant growth and some water helps recharge local groundwater levels. Tree densities and the diversity of woody species on rehabilitated land are usually higher than on adjacent land. This is because, where farmers invest in water harvesting techniques, they almost always also invest in improved soil fertility management. The manure or compost they use contains seeds of trees and bushes on which their livestock browse. If farmers decide to protect and manage the young trees which emerge together with their crops, they create a new agroforestry system in the process. The scale of land rehabilitation in Niger and Burkina Faso since the end of the 1980s is in the order of 500,000 ha. Land that used to be barren and degraded has become productive. Crop yields vary from a few hundred kg/ha in years of poor rainfall to up to 1.5–2 tons/ha in years of normal or good rainfall. The yield levels are not only determined by rainfall, but also by the quantity and quality of organic fertilizers used. Hardly any inorganic fertilizers are used. Land rehabilitation on the central plateau of Burkina Faso feeds an additional 400,000 people.

D. The role of external interventions and the potential for scaling up farmer-managed re-greening

External interventions have helped catalyse processes of re-greening, as in the Maradi Region in Niger in around 1985 by Tony Rinaudo, who worked for an NGO called Serving-In-Mission (Tougiani, Guero and Rinaudo, 2008). Other NGOs as well as an IFAD-funded project have also supported the spreading of farmer-managed re-greening and other best practices in natural resource management by organizing farmer-to-farmer study visits. During these visits, farmers (men and women) with experience in specific re-greening techniques are given an opportunity to discuss these with other farmers working under similar agroecological conditions. For instance, farmers from Burkina Faso have visited the large-scale on-farm re-greening in Mali's Seno Plains, and farmers from the Seno Plains have visited farmers in Burkina's Yatenga region to learn about soil fertility management practices.

The question is under what conditions can a rapid expansion of farmer-managed re-greening be expected? Based on experiences in Niger and Mali, rapid expansion can be catalysed if the following conditions exist: (i) high population density, because this induces resource users to intensify agriculture; (ii) sandy soils, as these can easily be penetrated by roots; (iii) current low on-farm tree densities; and (iv) enabling policies and legislation. Farmers will be more likely to invest in trees if they are given clear ownership rights to their trees. In 1985, all trees in Niger were owned by the State, but in 2011 the perception of farmers is that they have ownership of their on-farm trees. It is vital that such perceptions are supported by forestry laws.

E. Re-greening in the Horn of Africa

Kenya is the only country in Africa, and possibly in the world, in which the (new) constitution obliges farmers to grow trees on 10 per cent of their land. Relevant ministries are currently discussing how this could be implemented. Many farmers in the fertile highlands already have 10 per cent of their land under trees (*Grevillea robusta*), but this is not the case in Kenya's arid and semi-arid lands. Tree planting in drylands across Africa tends to have a dismal track record, with survival rates usually ranging between only 0 and 20 per cent.[6,7] The protection and management of on-farm natural regeneration in drylands, including in Kenya's drylands, will help increase the number of on-farm trees.

Even casual observers travelling to Tigray (Ethiopia) will be struck by the scale of natural regeneration in parts of this region. It is not easy to find data about the scale of re-greening, but it covers at least one million hectares. Most of the re-greening has occurred in what are usually called enclosures, which are degraded lands set aside for rehabilitation. A number of activities are combined in these enclosures: water harvesting techniques to get more water into the soil, natural regeneration and some enrichment planting, usually with exotic species. For instance, in the valley of Abraha Atsbaha, such activities led to an increase in water levels in the valley, which enabled the digging of several hundred shallow wells. In 2008, even when rainfall was very low and cereal cops failed, many families managed to cope better with drought

An enclosure and natural regeneration in the Tigray region (Ethiopia).

A dense stand of young Combretum glutinosum trees on Mali's Seno Plains annually produces tons of litter per hectare (March 2011).

because they were able to irrigate fruit trees as well as the vegetable gardens around the wells. What has been achieved in parts of Tigray since the early 1990s under adverse conditions is another of those re-greening successes in Africa's drylands that have largely gone unnoticed.

F. A Green Revolution in Africa or another kind of green revolution?

The current thinking about a Green Revolution in Africa involves increasing the use of chemical fertilizers and improved seeds, expansion of irrigation, mechanization and improving market access. However, the costs of chemical fertilizers are high and their use in drylands is not always efficient, as the soil's content of organic matter is low. The challenge is to first increase the organic matter, and the most efficient way of doing so is, in many cases, by increasing the number of on-farm trees. Trees can produce significant quantities of litter which helps maintain or improve soil organic matter content (as illustrated by the picture above). Farmers prune the trees early in the rainy season, which supplies firewood for cooking and reduces competition with crops. Moreover, the trees provide dispersed shade to the crops, which protects them part of the day against the sun. Farmers leave the pruned branches on the land until the leaves are sufficiently dry, after which the branches are collected for firewood, while the leaves are left behind on the land.

Farmers who have managed to increase the soil's content of organic matter would benefit greatly from small doses of inorganic nitrogen (N) fertilizer. Small-scale farmers in Africa (and elsewhere) who have limited financial resources but want to intensify their agricultural production have one major low-cost option, which is to increase the number of trees. Some drylands in Africa still suffer from the legacy of subsidized mechanization of the 1960s and 1970s, which stimulated the removal of on-farm trees. Even today mechanization and large-scale farms tend to be regarded by many policymakers as the way forward, despite the considerable damage it often does to the soils (as illustrated by the picture below).

A large mechanized commercial farm in Ethiopia's Rift Valley close to the town of Hawass, with a tractor ploughing the land (top right). The land does not have a single tree on it to protect it against the sun and wind. This field loses tons of topsoil every year due to wind and water erosion.

Commentary VI: Genetic Engineering and Biotechnology for Food Security and for Climate Change Mitigation and Adaptation: Potential and Risks

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Abstract

World hunger is a multifaceted problem that cannot be solved by technological changes alone.

Industrial agriculture is unsustainable, and technological adjustments based on genetic engineering have not been able to achieve the relevant Millennium Development Goals; instead, they have introduced products that restrict farmer-based innovation, in situ conservation and access to the best locally adapted germplasm.

Alternative agricultural models, such as agroecology, demonstrate potential to reduce poverty, increase food security and reduce agriculture's environmental footprint because they increase agroecosystem resilience, lower external inputs, boost farmers' incomes and are based on technologies that, for the most part, can be understood, implemented and further modified by poor and subsistence farmers.

Global food production is increasing faster than demand (IAASTD, 2009). Aside from price spikes in 2008 and 2010-2012, food prices have been at one hundred year lows (Nellemann et al., 2009). Despite this, billions of people are malnourished and a billion are starving (Hoffmann, 2011; Khan and Hanjra, 2009).

Current agricultural practices, including the harvesting of natural resources such as ocean fisheries, are having enormous and unsustainable environmental impacts (Khan and Hanjra, 2009; Rivera-Ferre, 2008). And increased agricultural production is putting pressure on ever-shrinking ecosystem services (Daily et al., 1998; IAASTD, 2009). These services are needed to maintain the productivity of land as well as fresh and salt water used to produce food (MEA, 2005; Tilman et al., 2002). The unfortunate feedback cycle is that as agriculture expands into ever more marginally productive ecosystems, its impact on climate change grows (Nellemann et al., 2009).

A. Hunger is a choice

The current failures to feed the world are not due to limitations of technology, but to social choices (Heinemann, 2009; IAASTD, 2009; Kiers et al., 2008). Importantly, these choices undermine the availability of balanced diets in areas where hunger and malnutrition are endemic (Nord, 2009).

The cost of food and the environmental cost of food production could be dramatically reduced just by cutting food waste. According to Nellemann et al. (2009: 7), "[D]eveloping alternatives to the use of cereal in animal feed, such as by recycling waste and using fish discards, could sustain the energy demand for the entire projected population growth of over 3 billion people" by 2050. Some of this waste from farm to fork could be reduced by technological advances, as well as by cutting consumer rejection before and after purchase, but mostly it could be overcome by a change in social policy and attitudes, especially among consumers in developed countries who waste up to 10 times the amount of food wasted in developing countries (Gustavsson et al., 2011).

Demand for food alone is not the only cause of agriculture's growing footprint. Many countries, even those experiencing famine, rely on the export of food to generate income (Vandermeer and Pefecto, 2007). In recent decades, large-scale conversions of the agroecosystem in some countries have been correlated with an increase in food insecurity, motivated by the push to produce more export commodities at the expense of foods of higher nutritional value for

Table 2. Changes in food security in Argentina

Food supply for human consumption (per person/day)	1990–1992	1995–1997[a]	2000–2002[b]	2005–2007[c]	1990–1992 to 1995–1997 (%)[d]	1995–1997 to 2000–2002 (%)[d]	2000–2002 to 2005–2007 (%)[d]
Dietary energy supply (kcal)	3,010	3,160	3,140	3,000	0.9	-0.1	-0.9
Total protein intake (grams)	95	100	99	94	1	-0.3	-0.9
Animal protein (grams)	61	64	63	62	0.9	-0.5	-0.3
Fat (grams)	106	113	110	108	1.2	-0.4	-0.5

Source: Based on data from FAOSTAT.
Notes: [a] Period of first introduction of commercial GM plants; industry figures report 1.7 million hectares of GM crops were being cultivated in 1996 (ISAAA Brief No. 36).
[b] According to industry figures, during this period, 13.5 million hectares of GM crops were being cultivated (ISAAA Brief No. 36).
[c] According to industry figures, during this period 19.1 million hectares of GM crops were being cultivated (ISAAA Brief No. 37).
[d] Annual rate of change – not total change over the period.

domestic consumption (Pengue, 2005; and table 2 above).

New or improved technologies could help feed the world (Heinemann, 2009; IAASTD, 2009). Before considering which technological approaches are best for reducing the effects of climate change on agriculture and mitigating agriculture's contribution to factors causing climate change (such as greenhouse gases), it will be essential to determine which problems are best solved by technological tools and which can be solved by changes in the socio-economic and socio-political status quo. This will entail considering some painful questions about the causes of the problems. Conspicuously, few are likely to have been caused by a lack of technology (*Nature*, 2010).

B. Choosing among technological paths to pro-poor, climate-resilient agriculture

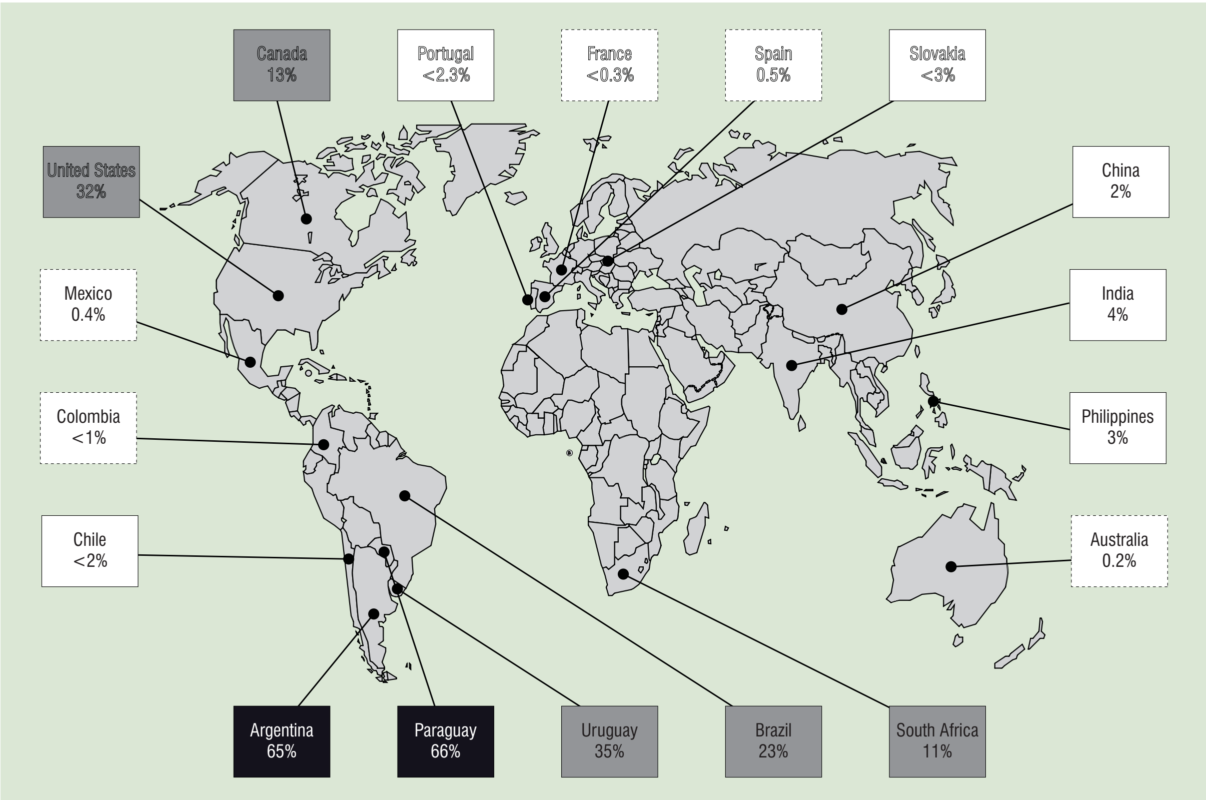
The right technology delivered in the right way should be able to help reverse agriculture's adverse impact on climate change, and ultimately contribute to food security (Heinemann, 2009; Scialabba, 2007a). Otherwise, proposed technological solutions to these problems will not be sustainable, make their fair contribution to the Millennium Development Goals or help distribute the benefits more equitably among the peoples of the world. As concisely stated by the Director of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), "business as usual is not an option".[9] One form of "business as usual" is the highly damaging traditional agricultural practice. Damaging traditionalist approaches are due more to the neglect of farmers than to farmers preferring to use them. Poor and subsistence farmers are challenged by a lack of adequate extension and community support services that disseminate knowledge, affordable financing and access to markets for the sale of surplus production.

Another form of "business as usual" is the intensive use of external inputs in agriculture, and, especially, support to massive monocultures, both of which are concentrated in developed countries and some rapidly industrializing developing countries. Unlike unsustainable traditional approaches, input-intensive agriculture – loosely referred to as conventional or industrial agriculture – has been promoted by policy decisions. The policies and technologies associated with industrial agriculture involve a shift in innovation resources from public control to the private sector (IAASTD, 2009; Spielman, 2007) as a result of the private sector investing more than the public sector in research and development. Private investment further leverages much of what remains of public investment through government policies that promote co-funding by the private sector, the pursuit of intellectual property (IP) by public sector institutions (e.g. universities and agriculture agencies), and public sector licensing of IP from the private sector (IAASTD, 2009; Vanloqueren and Baret, 2009). Industrial agriculture also receives large public subsidies (direct and indirect) in developed economies, which stifle producers and markets in developing countries and further undermine the ability of poor and subsistence farmers to intensify production and reduce their environmental footprint (Kiers et al., 2008; Spielman, 2007). Furthermore, industrial agriculture has neither produced a sustainable, highly productive agroecosystem nor curbed agriculture's impact on climate change.

Of the many biotechnology options available for testing or implementing, perhaps the one that receives the most attention is genetic engineering (GE) for the production of genetically modified organisms (GMOs) – plants, animals and microbes (IAASTD, 2009). As currently applied, GE has come to symbolize agricultural production systems that make intensive use of external inputs and promote monocultures (Rivera-Ferre, 2008). This is because of the types of commercialized GM products that are the most common (i.e. soybeans, maize, rapeseed and cotton), because of the particularly large agroecosystems that have adopted GM crops, mainly those in Argentina, Brazil, Canada, Paraguay, the United States and Uruguay (figure 5), and because of the most common commercialized GM traits: herbicide tolerance and insecticide production. Herbicide tolerance, in particular, lends itself to mechanized delivery of an inseparable co-technology, a chemical for weed management. This weed-control strategy requires large tracts of monoculture to avoid herbicide drift onto neighbouring or other agricultural land. Finally, because of the relatively small number of countries that have adopted GM crops and the few companies that have commercialized it, individual country- and company-specific policies and business plans have had an important influence on the adoption of this biotechnology.

That some of the largest agricultural countries in the world have adopted GM versions of a few crops

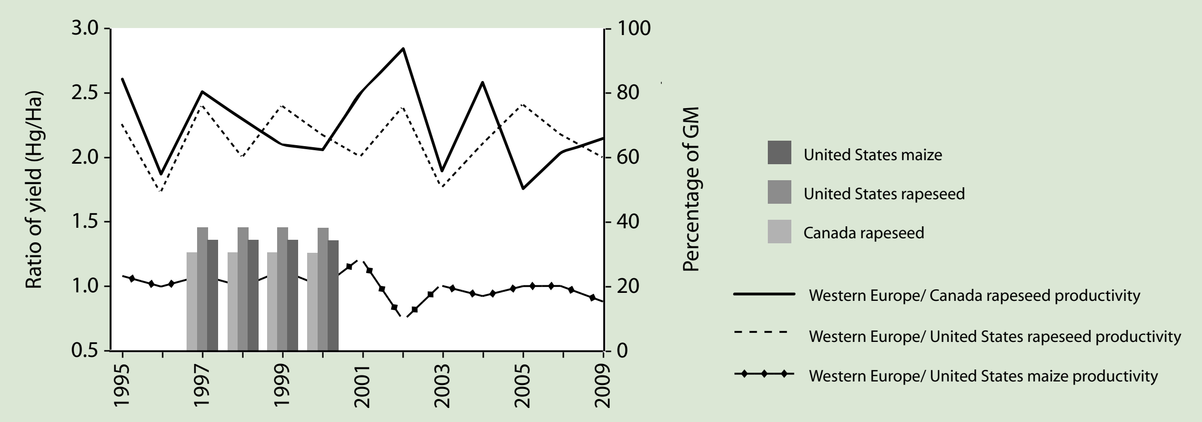
Figure 5. Degrees of commitment to GM agriculture (estimates for 2007)



Sources: Reproduced from Heinemann, 2009.

Note: Only two countries in the world have converted the majority of their agricultural systems to GM cropping (black boxes). According to industry figures, Argentina and Paraguay are true "mega countries" of GM crops (James, 2007). The majority of the top 20 GM producing countries commit less than 1–5 per cent of their agricultural production to GM (white boxes with solid lines indicate above 1 per cent). Even the world's largest producer, the United States, commits no more than about a third of its cropping capacity to GM (grey boxes for countries having more than 10 per cent).

Figure 6. Comparative yields in GM adopting and non-adopting agricultural systems, 1995–2009



Sources: FAOSTAT for ratio of yield; and GMO Compass for percentage of GM maize and rapeseed (accessed May 2011).

Note: Left axis is the ratio of yield in hectograms (Hg) per hectare (Ha) for two crops, rapeseed (top) and maize (bottom), and three producers, Western Europe, Canada and the United States. Right axis represents the proportion of GM by crop type in the North American agricultural systems.

should not be taken as evidence that GE has delivered sustainably and reliably greater yields. Contrasting North American and Western European production of maize and rapeseed is instructive in this regard because they both have high-input, high-production agroecosystems. In Canada, for example, rapeseed (canola), and in the United States, maize, are almost exclusively produced from GM plants. Collectively, Western Europe has shunned the cultivation of GM maize and rapeseed (figure 6). Yet maize yields are very similar in the two agroecosystems, and Western Europe's rapeseed yields are about double those of North America. This trend has not changed since the adoption of GM plants in North America.

Broadly speaking, countries making a substantial shift to GM crops are in a group where food security has either shown no improvement (e.g. United States), or where it is declining (e.g. Argentina). (figure 6; and Heinemann, 2009).

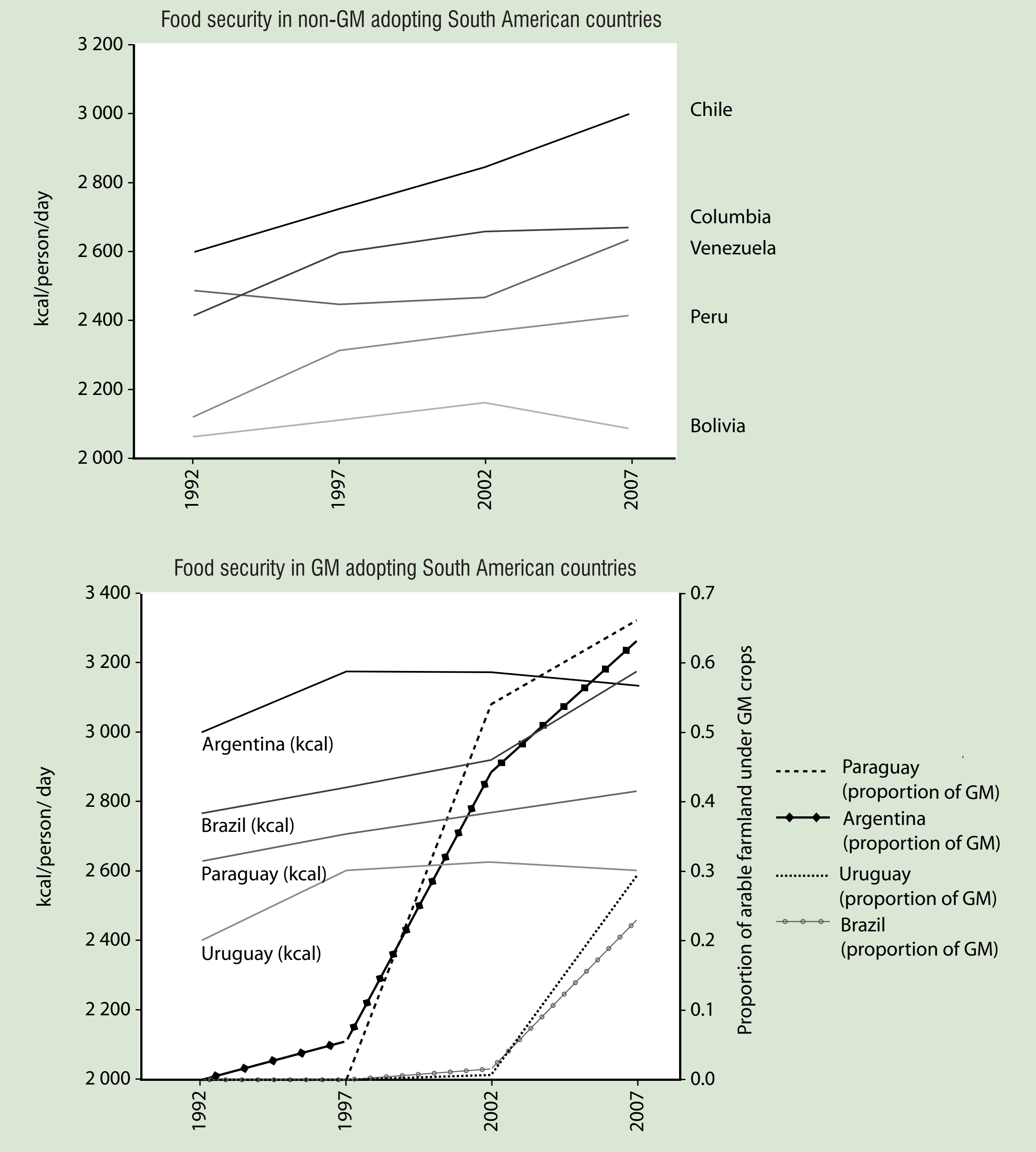
C. How some biotechnologies are failing

Arguably, some GM products have lowered the overall impact of industrial agriculture. For example, the use of glyphosate-based herbicides on GM crops has reduced the need for tilling as a weed control strategy (Pengue, 2005; Service, 2007). Similarly, the use of GM insecticide plants (often called Bt plants), particularly cotton, has reduced the use of external chemical insecticides.

Unfortunately, these benefits are both contested and deterministically unsustainable (Heinemann, 2009). The predictable pattern and quantity of glyphosate herbicide use in GM agriculture has caused the evolution of resistance in weeds on a scale never experienced in the decades of glyphosate use prior to GM crops, leading to a return to tilling and the use of other herbicides for weed control (Gaines et al., 2010; Powles, 2008; Service, 2007). Meanwhile, the unique pattern of use of glyphosate on GM soybeans has reduced *in situ* nitrogen fixation by chelating nickel, a required co-factor for enzymatic activities in the microbial symbionts (Zobiole et al., 2010), and reduced normal iron uptake and storage in soybeans (Bellaloui et al., 2009). Glyphosate on herbicide tolerant plants also reduces root biomass, elongation and lateral root formation (Bott et al., 2008). Systemic distribution of glyphosate throughout the plant is associated with increased susceptibility to colonization by disease-causing fungi (Kremer, Means and Kim, 2005). These effects further reduce the sustainability of GM approaches. Likewise, replacing complementary and diverse pest control practices, such as integrated pest management (Mancini et al., 2008), and the judicious use of natural sources of Bt insecticides, as in organic agriculture, along with the mass planting of GM Bt crops, is causing the appearance of secondary pests (Lu et al., 2010; Zhao, Ho and Azadi, 2011).

Moreover, whatever the comparative benefits of GE may be, they are largely lost when GE/

Figure 7: Food security in GM and non-GM adopting countries in South America compared, 1992–2007 (kcal/person/day)



Sources: FAOStat.

Note: A collection of South American countries that have not adopted GM-based agricultural systems show similar improvements in food security (top panel). Countries with varying proportions of GM (right axis, bottom panel) show mixed results. Those with rapid adoption of greater amounts of GM in their agriculture are more prone to increased insecurity levels (measured in kcal, left axis).

industrial agriculture is compared with alternative biotechnologies such as agroecological technologies (Pimentel et al., 2005; Pretty, 2001). Land converted to agriculture from other uses, guided by agroecology, requires time to condition and bring to full potential (Badgley et al., 2007; Pimentel et al., 2005). Once this has been achieved, agroecological approaches have been observed to generate higher yields than industrial agriculture, as shown in several compilations and meta-analyses at country, continental and global levels (Badgley et al., 2007; Uphoff, 2007). Plants grown on agroecological farms are more resilient to stress than those grown by means of industrial agriculture (Lotter, Seidel and Liebhardt, 2003; Pimentel et al., 2005). Agroecological farms require far less fossil-fuel-derived energy and sequester more carbon (Pimentel et al., 2005; Scialabba, 2007b). In addition, the adoption of agroecological approaches contributes to sustainable societies by reducing poverty and improving food security (Scialabba, 2007a; UNEP and UNCTAD, 2008).

After approximately 30 years of commercialization and pre-commercial GE research and development, it has not made a substantial contribution to sustainable agriculture. The IAASTD (2009) was therefore justified in questioning whether GE could deliver on Millennium Development Goals or reduce agriculture's contribution to climate change. However, had the incentives for delivering GM products been different, and the goals of public and private innovation not been so thoroughly intertwined in this biotechnology (Vanloqueren and Baret, 2009), would GE have produced different results? In other words, has GE failed because of policy decisions and its particular history of commercialization, or because the technology itself has been inappropriate?

D. Why some biotechnologies could succeed

Again, comparisons with alternative biotechnologies may be instructive for responding to these questions. The two biotechnologies being contrasted with GE here are conventional breeding, with or without marker-assisted selection, and agroecology. The traits considered are drought tolerance and nutrient enhancement.

1. Drought tolerance

Agriculture makes tremendous demands on groundwater, and water shortages are a global drag on food production. This has driven the search for plants that maintain or improve yield under conditions of water deprivation. Despite many attempts, to date there are no commercially available GM plants with traits that reduce the effects of abiotic stress (Heinemann, 2008). The closest so far is a variety of "drought tolerant" maize, called MON 87460, which is under regulatory consideration in some countries. According to the developer's data, the GM maize had a marginally ($p<0.05$) statistically significant increase in yield in only one of four field tests, which is unconvincing for the general expectation that the variety is higher yielding under stress. The developer claims that "the major component contributing to the improved yield of MON 87460 under water-limited conditions is the increased number of kernels per ear" (Monsanto, 2009: 45), rather than claiming that the variety produces more usable biomass. The developer calls this trait a change in "yield potential", rather than an increase in yield.

Drought tolerance has long been a goal of conventional breeding, and current hybrids already exhibit some tolerance (Monsanto, 2009), with improvements on this baseline expected. According to the World Bank (2007:162), the "International Maize and Wheat Improvement Center (CIMMYT), after more than 30 years of research to produce drought-tolerant maize varieties and hybrids, is now seeing results in eastern and southern Africa. Evaluated against existing hybrids, the new ones yield 20 percent more on average under drought conditions. Similarly, recent evidence points to significant yield gains in breeding wheat for drought and heat-stressed environments."

Agroecological approaches further reduce the need for intensive breeding or GE to produce drought-tolerant varieties. Increasing the organic matter in soil, using cover crops and interspersing fallow years significantly increases latent soil moisture, making agroecological farms far more resilient to drought-related stress (Heinemann, 2008). Water percolating through the soils in agroecological test plots has been reported to be between 15 per cent and more than 30 per cent higher than in conventional plots under drought conditions, and has demonstrated commensurate increases in yields compared with matched conventional management (Lotter, Seidel and Liebhardt, 2003; Pimentel et al., 2005; Scialabba, 2007a).

2. Nutrient enhancement

Micronutrient deficiencies contribute significantly to malnutrition (Scialabba, 2007a), which is why developing plants that are enriched with micronutrients has been a long-term goal. It is therefore particularly unfortunate that the largest group of commercialized GM plants, those tolerant to glyphosate herbicides, are also less able to take up some important micronutrients from the soil (Bellaloui et al., 2009; Bott et al., 2008). Importantly, spray drift at non-lethal concentrations has a similar effect on non-GM crops (Bellaloui et al., 2009). Because glyphosate can be used multiple times during the growing season on herbicide tolerant GM plants, non-GM crops are now routinely exposed to spray drift.

Attention has been drawn to the development of GM rice that produces ß-carotene, which can be converted by humans to vitamin A (Heinemann, 2009; Schubert, 2008). However, high micronutrient varieties are not unique to GE; for instance, maize lines that produce nearly four times the amount of ß-carotene (8.57 $\mu g\ g^{-1}$) of second generation GM rice varieties (2.6 $\mu g\ g^{-1}$) have been developed through conventional breeding (Yan et al., 2010). This is mentioned not to disparage the technical achievement of introducing the biosynthetic pathway for ß-carotene into rice, but to emphasize the importance of protecting crop genetic diversity and its ongoing potential to be tapped for use in balanced diets (Zamir, 2008).

Combined studies have found that balanced diets are more accessible to poor and subsistence farmers using agroecological rather than industrial farming approaches. This is because of the use of multicropping and the integration of livestock rearing, and the higher micronutrient content of the plants they grow, and because these farmers tend to earn more, which allows them to purchase other foods (Scialabba, 2007a; UNEP and UNCTAD, 2008).

Proponents of ß-carotene-enriched GM rice argue that safety regulations have been the primary hindrance to the transfer of this product to poor and subsistence farmers in societies that suffer from significant vitamin A deficiency (Dubock, 2009). However, malnutrition is caused by the lack of a balanced diet rather than the lack of access to GM crops. Moreover, these commentators neglect to take into account the estimated 70 patents and 32 patent holders that had to agree to the use of their intellectual property prior to release of the GM rice (Graff et al., 2003; Spielman, 2007; WHO, 2005). These protracted negotiations were recently resolved with an agreement that exempted specified countries from having to pay royalty fees for growing this variety of GM rice provided that the rice was not exported (GRO, online). Given the difficulties in containing transgenes, including those in rice (Vermij, 2006), this humanitarian licence may transfer liability for gene flow and potential patent infringement to the farmer and the adopting country (Heinemann, 2007). Non-GM varieties and agroecological technologies are usually protected by less restrictive IP instruments, and as process innovations are not prone to accidental and unavoidable escape in the way that seeds and pollen are, this liability would not be incurred through their use.

E. Conclusions

Technological solutions are rarely sustainable if they do not rectify the cause of the problem. Regardless of the ability of industrial agriculture to produce food surpluses in previous decades (Rivera-Ferre, 2008), future technologies must produce sustainable solutions and be useful to those who are now malnourished. As stated by Uphoff (2007: 218), “The most direct way to reduce poverty is to raise the productivity of those factors of production controlled by the poor: first of all, their labor, but also their knowledge and skills, and for many though not all, small areas of land. Increased factor productivity of land, labor, capital and water can have second-order benefits for the poor, urban as well as rural, by lowering the price of food and other things on which the poor spend most of their meager incomes.” The export of the industrial model of agriculture and its associated GE-based technologies that are embedded in particularly exclusionary IP instruments, such as patents, to food-poor countries shows little promise of addressing the needs of the hungry poor (IAASTD, 2009; Pray and Naseem, 2007; WHO, 2005; World Bank, 2007).

Fortunately, other technologies show promise, both for increasing yield in yield-limited agroecosystems and for promoting what the present system has not been able to achieve, namely sustainable societies in poor countries (Rivera-Ferre, 2009; UNEP and UNCTAD, 2008). This is obtained when technologies reduce external inputs and on-farm costs of seeds, incorporate multicropping and livestock for balanced diets, promote ongoing farmer innovation under an appropriate IP rights framework, and are produced by a public sector that offers the appropriate incentives (Heinemann, 2009; Vanloqueren and Baret, 2009).

Climate change has been rapid, but not unpredictable; indeed, its occurrence has often been predicted even if the message has been resisted for decades. Likewise, a familiar message for decades has been that agriculture is making unsustainable demands on ecosystem resources worldwide, and is contributing to climate change. One of the most important lessons to be learnt before deciding on a technological pathway to reduce agriculture's appetite for resources and its footprint on the climate is that early warning of deleterious but avoidable outcomes need to be taken seriously, rather than ignored as in the past. If we allow the same voices to be drowned out again, we will fail to protect those who will suffer the most from climate change and its damaging effects on agricultural production.

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Notes

1 As aptly stated by Rundgren (2012), "How we discuss 'efficiency' or 'productivity' and 'technology' has strong biases, clearly visible in agriculture, where the systems that waste most, pollute most and use much external energy are those that are considered 'modern', 'efficient' and 'productive'. The function of technology to put other peoples' resources in the service of the already wealthy, and to constantly increase the gap is obscured by our myths about 'progress'".

2 *Sustainable or green agriculture* refers to the increasing use of farming practices and technologies that simultaneously: (i) restore, maintain and increase farm productivity and profitability while ensuring the provision of food on a sustainable basis, (ii) reduce negative externalities and gradually lead to positive ones, and (iii) rebuild ecological resources, i.e. soil, water, air and biodiversity ("natural capital" assets) by reducing pollution and using resources more efficiently. Green agriculture is exemplified by a diverse, locally adaptable set of agricultural techniques, practices and market branding certifications. Examples of these include organic agriculture and agroecology (referred to preferentially in this article as an approach to agriculture based on the principles and science of ecology, for meeting people's need for food which gives equal attention to the goals of sustainability, resilience and equity – and not only to production – which represents more accurately the transition goals to multifunctional agriculture) (modified from UNEP, 2011). The principles underlying sustainable or "green farming practices and technologies" include: (i) restoring and enhancing soil fertility through the increased use of naturally and sustainably produced nutrient inputs, diversified crop rotations, and livestock and crop integration; (ii) reducing soil erosion and improving the efficiency of water use by applying minimum tillage, and cover crop cultivation techniques; (iii) reducing the use of chemical pesticides and herbicides by implementing integrated biological pest and weed management practices; and (iv) reducing food spoilage and loss by improving post-harvest storage and processing facilities (modified from UNEP, 2011).

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4 For an example of Mali's Seno Plain, see ARI update 2011 no.4 at: www.africa-regreening.blogspot.com.

5 The lower on-farm tree densities in northern Nigeria may be due to differences in tree ownership.

6 Personal communication with foresters across the Sahel.

7 This makes it hard to explain why governments and donor agencies, at least until recently, stubbornly continued to support and promote tree planting. It is more rational to promote natural regeneration and to plant only those tree species that do not regenerate spontaneously, but which resource users would like to have on their fields.

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9 See: www.agassessment.org/docs/NAE_press_release_final.doc.