

Food security in the context of energy and resource depletion: Sustainable agriculture in developing countries

Cornelia Butler Flora*

Iowa State University, Ames, IA, USA.

*Corresponding author: cflora@iastate.edu

Accepted 15 February 2010; First published online 25 March 2010

Research Paper

Abstract

Food insecurity remains high in most of sub-Saharan Africa. That insecurity is made even more acute by the increasing scarcity and degradation of natural resources. Low soil fertility is a consistent problem faced by agriculturalists and herders. The dominant international thrust to increase food production has been to stimulate trade, enhanced by technology and its transfer. While international bodies acknowledge the importance of small farmers, they operate as if improving the technologies, trade regimes and value chains that are characteristic of industrial agriculture will have the same results in local ecosystems in developing countries. Price volatility makes access to purchased inputs more risky for smallholders and the governments that subsidize those inputs. The diverse local contexts that serve as the base of African agriculture are thus assumed to be overridden by technology. In contrast, a systems approach that focuses on sustainability of the local ecosystem, social and cultural relationships and economic security can be as, or more productive than industrial agriculture and have a much better opportunity to increase food security in developing countries. Such a systems-based shift in practices, such as the application of conservation agriculture and integrated systemic approaches in Millennium Villages, have potential of addressing household livelihood strategies and production issues in a sustainable, farmer-based way. Resource-conserving agriculture has been shown to increase yields in developing countries. Priority should be given to developing technologies that follow the systems principles of sustainable agriculture, integrating biological and ecological processes (such as nutrient cycling, nitrogen fixation, soil regeneration and biodiversity) into the production processes; minimizing use of non-renewable inputs that cause harm to the environment or to the health of farmers and consumers; and making productive use of the knowledge and skills of farmers and their collective capacities to work together to solve common problems. A variety of models are on the ground in Africa, and there is political will in the African Union to increase investment in agriculture. What sort of investments, policy interventions and capacity building are more effective in increasing productivity and the well-being of agricultural producers? Are strategies aimed at reducing the number of people involved in farming and herding viable in the context of a stagnant world economy?

Key words: trade, technology, sub-Saharan agriculture, sustainable agriculture, systemic approaches

Introduction

The twin shocks of climate change and globalization have decreased food security in many developing countries in the past two decades. As natural resources, including soil quality, biodiversity and water quantity and quality decline, international institutions and nation states have become aware of the importance of agriculture in addressing the instability that comes with lack of food security. Climate change in sub-Saharan Africa exacerbates the impacts of droughts, soil degradation and decline in biodiversity.

Even though African agricultural production increased in 2009 for the first time in decades, food security remains a huge issue, embedded in nearly 20 years of neglect of the agricultural sector on the assumption that market forces could generate the momentum needed for appropriate infrastructure, research, technical assistance and marketing linkages once the barriers to international trade were removed.

International bodies posit two distinct paths to food security: one depends on industrial agriculture and international trade and the other on sustainable agriculture and

local food systems. This paper presents these two approaches and their potentials for increasing food security in developing countries, with particular focus on sub-Saharan Africa.

Evolution of Recent International Approaches to Food Security

A period of structural adjustment began in the 1980s. The World Bank, the International Monetary Fund and regional multilateral banks such as the African Development Bank required countries to deeply cut government spending, privatize state services and open their markets to international trade in order to be deemed credit-worthy. Credit-worthiness was necessary in order to refinance huge debts incurred during the rapid increase in the price of natural resources in the 1970s¹. That modernization model, based on a shrinking national government, resulted in the elimination or privatization of extension services in many developing countries and a focus on large-scale input-intensive agriculture and imports from developed countries. At the same time, food security declined, particularly in sub-Saharan Africa. The productionist paradigm of increasing the production of a few crops, primarily grains and cotton, on large and expanding, input-intensive farms kept grain and cotton yields steady, but hunger increased in many parts of sub-Saharan Africa.

In 1996, the Rome Declaration on Food Security² acknowledged that food insecurity is more than inadequate food production. It recognized poverty as a major cause of food insecurity, and related poverty to lack of human rights. The Rome Declaration committed its signatories to the following goals:

- ensure an enabling political, social and economic environment designed to create the best conditions for the eradication of poverty and for durable peace, based on full and equal participation of women and men;
- implement policies aimed at eradicating poverty and inequality and improving physical and economic access by all, at all times, to sufficient, nutritionally adequate and safe food and its effective utilization;
- considering the multifunctional character of agriculture, pursue participatory and sustainable food, agriculture, fisheries, forestry and rural development policies and practices in high- and low-potential areas, which are essential to adequate and reliable food supplies at the household, national, regional and global levels; this includes combating pests, drought and desertification;
- strive to ensure that food, agricultural trade and overall trade policies are conducive to fostering food security for all through a fair and market-oriented world trade system;
- endeavor to prevent and be prepared for disasters of both human and natural origin and to meet transitory and emergency food requirements in ways that encourage

recovery, rehabilitation, development and a capacity to satisfy future needs;

- promote optimal allocation and use of public and private investments to foster human resources, sustainable food, agriculture, fisheries and forestry systems and rural development, in high- and low-potential areas;
- implement, monitor and follow-up this Plan of Action at all levels in cooperation with the international community.

In 1996, it was clear to the policy-makers at the Rome meetings that industrial agriculture alone was not the solution to the problem of food insecurity, but that structural issues and local empowerment for sustainable agriculture needed to be included in the strategies implemented.

Despite good intentions, food insecurity, particularly in developing countries, increased. The United Nations Millennium Declaration of 2000³ and its eight associated goals did not include increasing food security as a core strategy. Instead, Goal 1 was to eliminate poverty, presumably assuming that food security follows an increase in purchasing power. During the first decade of the Millennium Development Goals (MDGs), bilateral and multilateral investments in agriculture in developing countries decreased, with the Rockefeller Foundation one of the few continuing funders of agricultural capacity building in sub-Saharan agriculture.

The United Nations (UN) strategy defined reducing trade barriers as the primary instrument for making sure that industrial agriculture could 'feed the world'. In the meantime, the costs of inputs for industrial agriculture—seeds, fertilizers, pesticides, machinery and fuel—increased dramatically, and the costs of transportation made such an approach even more expensive.

The African Union was more concrete in increasing its capacity to confront food insecurity. Through the New Partnership for Agricultural Development (NEPAD⁴), established in July of 2001, the African Union set up the Comprehensive Africa Agriculture Development Programme (CAADP) in November of 2002, based on four pillars: (1) land and water management; (2) market access; (3) food supply and hunger; and (4) agricultural research. That document required substantial redirection of national budgets to enhance agriculture⁵. It was followed in 2004 by the Sirte Declaration on the Challenges of Implementing Integrated and Sustainable Development on Agriculture and Water in Africa⁶.

In 2002, responding to NEPAD, the G8, composed of the world's leading industrial nations, including France, USA, UK, Russia, Germany, Japan, Italy and Canada, met and drafted the African Action Plan⁷ and determined to support it financially. In the first peer review of the African Action Plan in 2003, the USA and Russia were the only states who had not yet acted on it⁸.

In 2002 the Bush administration in the USA implemented the *Presidential Initiative to End Hunger in Africa* (IEHA)⁹ to comply with the US government's G8

commitments to support the African Union's CAADP. The IEHA Initiative

... focuses on smallholder-based agricultural systems and their linkages to markets, the essential elements in reducing hunger in Africa on a sustainable basis.

The initiative was designed to rapidly increase agricultural growth, rural incomes and food production in sub-Saharan Africa by harnessing the power of new agricultural production and processing technologies; improving the efficiency of agricultural trade and market systems; building the capacity of community and producer organizations; and integrating the vulnerable into development processes. The IEHA initiative sought to increase trade, enabled by public-private partnerships and new value chains, with a shriveling of support for African agricultural research outside of agribusiness and biotechnology. Public sector research, stressed by CAADP, was downplayed in the US efforts. However, Kofi Annan called for a 'uniquely African Green Revolution in the 21st Century, in Addis Ababa in June 2004, with an emphasis on agricultural research in African by Africans'¹⁰.

A more comprehensive approach to agricultural development, based on the uniqueness of local ecosystems and cultures, was introduced in August 2002, at the World Summit on Sustainable Development (WSSD)¹¹ in Johannesburg. FAO and the World Bank charged a multi-stakeholder group of organizations, including FAO, GEF, UNDP, UNEP, WHO and UNESCO, and representatives of governments, civil society, private sector and scientific institutions from around the world to carry out a global consultative process to systematically assess the role of agricultural knowledge, science and technology in developed and developing regions of the world. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)¹² was the resulting structure.

The panel of participating governments received and accepted the proposed structure and process at the IAASTD Intergovernmental Plenary held in Nairobi from 30 August to 3 September 2004. They agreed on the objectives, goals, scope, key questions, design, preparation and peer-review processes, outputs, timetable, budget and governance structure. The principles and procedures were revised and approved at the Second IAASTD Bureau (governing board) meeting in Montpellier, France from 25 to 27 May 2005. The process, involving hundreds of volunteer scientists from around the world, took nearly two and a half years to complete, including the writing and rigorous review process.

The process included a number of unique elements that contributed to its ability to address food security based on distinct local realities, according to IAASTD, which included

- well-defined user needs grounded in an international consultative process;
- inclusion of hundreds of experts from all relevant stakeholder groups;

- multi-thematic focus embracing nutritional security, livelihoods, human health and environmental sustainability;
- multi-spatial: global and sub-global assessments with an intellectually consistent framework;
- multi-temporal: historical to long-term-future (until 2050) perspectives employing use of plausible scenarios;
- integration of local and institutional knowledge;
- assessment of policies and institutional arrangements, as well as knowledge, science and technology¹³.

The final report was approved by a majority of the participating governments and institutions in Johannesburg, South Africa, in April of 2008. It challenged the dominant transfer of technology (TOT) approach to agricultural development. 'The Transfer of Technology (TOT) model has been the most dominant model used in operational arrangements and in policy. However, the TOT model has not been the most effective in meeting a broader range of development goals that address the multiple functions and roles of farm enterprises and diverse agroecosystems'¹⁴. The report also concluded that local food systems, known to sustain livelihoods at micro level, are currently challenged by globalized food systems.

However, the document's cautionary approach to introducing genetically modified organisms (GMOs) and call for a shift in the dominant paradigm of agricultural development meant that the USA, Canada and Australia did not sign the final document¹⁵. The possibility of co-existence of technology- and market-driven agriculture with generalized solutions to production and distribution, with ecosystem-based agriculture with particular solutions for production and distribution, was thus challenged. The document and its regional reports initiated debates that challenged the current agricultural development model of trade and technology, beginning in Namibia in February of 2009. The report opened the door for considering the potential for agroecology and conservation agriculture as alternative development models that engaged local populations with a systems approach.

The World Bank's World Development Report 2008: Agriculture for Development¹⁶ brought the issue of food and agriculture front and center on the World Bank development agenda. The report reasserted agriculture's importance in the economic development process, particularly for less-developed, agriculture-based economies such as those in sub-Saharan Africa, but also for what the report calls the 'urbanizing' economies of regions such as Latin America. The report notes the particular importance of small-scale agriculture in poverty reduction: 'Improving the productivity, profitability, and sustainability of small holder farming is the main pathway out of poverty in using agriculture for development'¹⁶. The report points to the many market failures in the international agricultural economy and calls on governments and international agencies to increase the assets of poor farmers (particularly through access to land, water, education and health care), to raise the productivity of smallholders,

and to generate opportunities in the rural non-farm economy.

Its focus, despite reiterating the importance of agriculture for development, reflects the trade and technology approach, thus reinforcing a policy complex that has been a major barrier to rural poverty reduction through support of smallholder agriculture.

Trade continued as the keystone of agricultural development in this important document. The World Bank report called for deeper liberalization in agricultural trade, a strategy Pérez and colleagues found to be detrimental to food security in Latin America¹⁷. Agricultural exports increased dramatically. Yet the impacts on rural areas were limited or negative. In the case of soybeans, few of the benefits go to rural communities. Based on high-input, industrialized monoculture farming, employment and wages have both declined despite rising production. Ecological harm from agricultural expansion onto sensitive lands leaves lasting damage.

An increase in demand for meat in emerging countries, a sharp increase in petroleum prices and expanded energy uses of grains, oilseeds and sugar cane for fuel, brought a dramatic increase in food prices, which was made worse by speculation and hoarding¹⁸. The G8 group drafted the L'Aquila Food Security Initiative¹⁹ in response to the perceived need to increase food security to maintain political stability. The United Nations World Food Summit in November of 2009 in its report on the State of Food Insecurity in the World: Economic Crises—Impacts and Lessons Learned²⁰ ratified the following principles to advance global food security:

1. Comprehensively address the underlying causes of hunger and under-nutrition.
2. Invest in country-led plans.
3. Strengthen strategic coordination.
4. Leverage the benefits of multilateral institutions.
5. Make sustained and accountable commitments.

The types of investments, strategic coordination and the multilateral institutions to carry them out are not defined. To what degree is this renewed commitment to increase food security, which decreased over the past 15 years, a continuing commitment to industrial agricultural solutions? And to what degree is there recognition that, in a world of increasing resource scarcity, more sustainable agricultural systems must be established?

Food Insecurity

Food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life²¹. The unit of analysis of food security varies from the individual, household, community, nation, region or continent. The larger the unit of analysis, the more emphasis on trade and technology (particularly genetically modified crops) as the solution for food insecurity; while with the smallest unit, the greater the emphasis on

individual solutions, such as a family in the developed world giving money to support a child in the developing world²². The meso level of analysis, the community, forces the researcher and policy-maker to focus on the particular socio-economic and ecological factors that promulgate or work against security, as well as strategies to enhance food security for all individuals and households in the community. Increasingly, research in sustainable agriculture focuses on nested systems. Such research looks at a single component only in the context of the field, which is part of a farm, which is part of a watershed. Adaptive management is a method of addressing the embeddedness of systems levels²³.

Millennial Development Goal 1²⁴ has a target that could be seen as leading to food security: eradicate extreme poverty and hunger. One of the targets under that goal is to reduce by half the proportion of people who suffer from hunger (Target 1c). The indicators of reaching that target on a national basis involve substantially reducing:

Indicator 1.8: Prevalence of underweight children under 5 years of age

and

Indicator 1.9: Proportion of population below minimum level of dietary energy consumption.

Food security in 2010 is a central concern of unilateral and multilateral development agencies. Most official efforts focus on the intersection of food supply and access. While some efforts look at regional and local food-value chains, there is still a predominance of emphasis on increasing global gross productivity through enhanced generic germ plasm (seed technology) rather than local systems approaches, which may or may not require improved genetics to combat the overriding issues of low soil fertility:

The global community often uses the term 'food security' to describe not only the availability of food, but the ability to purchase food. Food security means having a *reliable* source of food and *sufficient* resources to purchase it. A family is considered food secure when its members do not live in hunger or fear of starvation²⁵.

After many years of systematic underinvestment in African agricultural capacity building by USAID and multilateral donors, the Obama administration in the USA, while still stressing food aid as a response to increasing food prices, is again investing in public-sector agricultural production and capacity-building efforts. Coupled with efforts by the African Union, there is hope that agricultural development investments in food security will go beyond the production of food through genetically modified seed and high inputs, the second Green Revolution focus, and beyond international movement of food, where arguments for decreasing trade barriers focus. To be effective in times of increasing resource scarcity, these efforts must examine where, how and by whom food is produced, processed and distributed.

The CAADP and the Sirte Declaration on Agriculture and Water are at the heart of efforts to increase food

security by African governments under the African Union. CAADP focuses on improving food security, nutrition and increasing incomes in Africa's largely farming-based economies. It aims to do this by raising agricultural productivity by at least 6% per year and increasing public investment in agriculture to 10% of national budgets. As a program of the African Union, it emanates from, and is fully owned and led by, African governments²⁶. A commitment of 10% of African governments' national budgets to agriculture is a dramatic increase for most of those countries, which have moved from food exporters to food importers. Members of CAADP are not of one mind as to how to implement their four pillars, in terms of investments in alternative research and technologies.

The question then becomes: what is the strategy that will best increase food security in an era of resource depletion?

Technological and Trade Solutions

The twin arguments of producing more staple crops under the best soil and water regimes and shipping them to areas of resource scarcity require the incorporation of new technologies of production and distribution. When one assumes that the problem of food security is underproduction, the solution is defined by a neo-Malthusian interpretation that under an exponential population increase and flat or arithmetic increase in food production, technologies that increase production per unit of land and unit of water seem particularly attractive. And if food is produced, it must move to those who will consume it. Thus attention to trade and value chains—the various connections between the input producers, distributors, retailers, farmers, intermediaries, food processors, wholesalers and retail—have been areas of research, international investment and policy making during the first decade of the 21st century.

Trade

The 1996 Rome declaration had a few lines about trade that emphasized its role in providing food security, stating, 'We agree that trade is a key element in achieving food security'²⁷. But the focus was on developing countries dropping tariff on imported goods rather than the USA and the EU eliminating agricultural subsidies. The overproduction of subsidized commodities lowered market prices, requiring even greater state investments to maintain the income of farmers who, because of the subsidies, received no market signal to produce less. The over-supply problem of developed countries (surplus production due to subsidies) became a solution to the food security issues of developing countries. Instead of viewing subsidy-generated surplus as inappropriate government payments for a few monoculture commodities, the overproduction became defined as 'feeding the world'. Insisting on trade without tariff barriers shifted the responsibility for making sure the value chains between developed country input suppliers, farmers,

intermediaries and food aid for developing countries operated smoothly. The public subsidies for international transport of commercial and surplus agricultural production in developed countries were turned from a political to a humanitarian action.

In the case of the USA, those subsidies included Farm Bill-mandated Market Access Program, Market Development Programs, Export Credit Guarantees, Export Subsidy Program and Trade Adjustment Assistance for Farmers and the food aid programs of PL480 (Food for Peace) and the McGovern–Dole International Food for Education and Child Nutrition Program, which includes costs of buying commodities, packaging, fortification, enrichment and preservation of those commodities, international transportation, and transportation, storage and management within the recipient county. Other non-USDA polices include soft credit programs to countries that import US commodities, subsidies for transportation in US flag shipping vessels, subsidies for barge transportation on navigable US rivers, as well as all that is necessary to maintain as many rivers as possible as navigable, allowing grains to be barged to ports for export and nitrogen to be barged up river to grow more corn.

The Ki–Moon–Clinton statement on Partnering for Food Security includes 'agricultural development, research, trade, social safety nets, emergency food assistance, and nutrition'²⁸. These provisions insure that such US policies encouraging the export of overproduction retain international approval.

The industrial model is justified by producing quick short-term gains, despite the increasing expense to national governments and especially international donors. Initiatives focusing on the subsidization of high-yielding seeds and fertilizers are supported by key international organizations, governments and stakeholders. For example, Malawi increased fertilizer subsidies and increased production²⁹. But the increase is totally dependent on a continuing flow of external inputs, often from different continents. By 2010, it had turned into a lucrative business, as the fertilizer was smuggled to Zambia for high profits by top officials and traders³⁰. Ricker-Gilbert, Jayne and Black suggest that targeting subsidized fertilizer to the poorest farmers would be most cost effective³¹.

It is clear that inputs are needed. In 2006 at the African Fertilizer Summit³², African heads of state committed to take concrete steps to ensure that farmers will have access to fertilizer and seeds, credit and irrigation facilities, better transport means and extension and market information services. Major issues involve how those inputs can be sustainably generated in order to increase and maintain food security, rather than national balance of payments through exports of food and fiber.

Trade and dependence on outside sources of food is not a viable option for much of Africa. 'A dozen countries of sub-Saharan Africa with a combined 200 million inhabitants have insufficient foreign exchange and access to ports to meet their food needs through imports'¹⁶.

Development Technologies Appropriate to Complex Adaptive Systems

What sorts of technologies make sense for smallholders in sub-Saharan Africa? Because they often farm on the most degraded soils, improving soil quality is imperative. But what sorts of mechanisms can respond to pests, drought and flooding? Should these solutions be primarily mechanical, in terms of crop rotations, improving soil tillage and conservation techniques? What is the role of improved genetics, either through traditional plant breeding or the introduction of extra-species genetic characteristics to a traditional food crop?

The 2009 Declaration of the World Summit on Food Security³³ carefully mentions the adoption of biotechnology as a logical response to limited resources.

We recognize that increasing agricultural productivity is the main means to meet the increasing demand for food given the constraints on expanding land and water used for food production. We will seek to mobilize the resources needed to increase productivity, including the review, approval and adoption of biotechnology and other new technologies and innovations that are safe, effective and environmentally sustainable.

How do African institutions respond to the pressures of multinational seed companies eager to participate in the subsidies that would make their seeds, pesticides and fertilizers available to small farmers? The Alliance for a Green Revolution in Africa (AGRA) is the major non-governmental organization (NGO) investing in African agriculture, with funding from such private donors as the Rockefeller Foundation, the Bill and Melinda Gates Foundation and multi-lateral and bi-lateral public institutions, including the World Bank and USAID. AGRA makes it clear that improved seed and the higher inputs they require are critical for Africans to increase productivity and thus food security, an approach echoed in the Millennium Villages Project³⁴. They stress sustainable agriculture and small farmers in their literature, with an emphasis on improved seeds as part of the entire value chain. Improved seed relies on increasing the number of African scientists conducting biotechnology-based research to overcome specific barriers to production. These improved varieties must be inserted in a responsive, dispersed distribution system³⁵.

Akinwumi Adesina, Vice President of AGRA, made their technology and trade approach clear in a speech at the United Nations Conference on Trade and Development (UNCTAD) on 30 June 2009, in Geneva, Switzerland:

Our vision cannot be realized without science and technology that serves the needs of Africa's millions of smallholder farmers. It cannot be realized without an enabling policy environment, on matters of trade and development, at global, regional and national levels. Only with such an environment will the benefits of science and technology reach Africa's millions of smallholder farmers, who grow the vast majority of our staple crops³⁶.

The technology and trade approach to increasing small-farm productivity is illustrated through AGRA's work in Ghana. The Ministry of Food and Agriculture and the Environmental Protection Agency of Ghana, in collaboration with AGRA and the International Centre for Soil Fertility and Agricultural Development (IFDC), officially certified 594 agro-dealers at Ejisu in the Ashanti region³⁷. They hope to use improved seed achieved through biotechnology as the basis of market-based solutions to agricultural productivity. The project, Ghana Agro-Dealer Development (GADD) is 'a 3-year initiative that will train approximately 2200 agro-dealers and seed producers in business management skills to help them grow their business and provide farmers with knowledge and information that will increase their production. The GADD project hopes to increase farm productivity, incomes and well-being of 850,000 small holder farmers by making seeds, fertilizers and crop protection products more accessible and affordable for farmers in the rural areas of Ghana'. Hopefully, it will also build on the systems that are in place in order to systematically increase soil fertility through rotations and continual ground cover.

Europe and many African countries have been hesitant to adopt GMO crops, in part because of the precautionary principle that keeps a number of European nations from purchasing them. That serves as a deterrent to African nations considering adoption of cross-species engineered crops for export. Genetically modified crops are appropriate in some contexts, unpromising in others and unproven in many more. The potential of genetically modified crops to serve the needs of the subsistence farmer is recognized, but this potential remains unfulfilled^{38,39}.

Sustainable Agriculture

The 1996 Rome Declaration included numerous references to sustainable agriculture, which it linked to smallholder production. There was no mention of systems for supporting sustainable smallholder production. The 2009 UN Declaration of the World Summit on Food Security linked sustainable agriculture and food security to sustainable agricultural systems. IAASTD found that systems approaches were critical for intensified sustainable agriculture. Compared to component technology approaches, systems approaches do not favor large-scale agriculture.

Wiggins found that scale is not an advantage in African agriculture:

... amongst the higher performing countries are several where the bulk of output comes from small farms—Ghana, Burkina Faso, Niger, Mali, etc. There is another observation: those countries that have, or have had, notable large-farm sectors—Namibia, South Africa, Zimbabwe—are well down the growth ranking; and others with smaller but significant large farm sectors such as Kenya and Zambia are not amongst the fastest growing agricultures⁴⁰.

Sustainable agriculture is not just substituting or removing industrial inputs. It involves system redesign⁴¹. Thus the

often-asked, presumably rhetorical question, 'Can organic agriculture feed the world?' must be qualified by the understanding that industrial agriculture is not feeding the world, as the number of food-insecure individuals is more than 1 billion in 2009, and that number is increasing. A number of studies suggest that there is great potential for localized systems approaches to feed the world⁴².

Rasul and Thapa⁴³, in their research in Bangladesh, found that ecological agriculture is relatively more sustainable than industrial agriculture, both environmentally and economically. However, they take a nested systems perspective and understand that the industrial agriculture socio-technical regime would have to change. 'Ecological agriculture could become an alternative if market distortions created by subsidies were removed, and financial benefits were provided to resource-conserving farmers along with necessary support through extension, credit, research, and marketing'.

Sustainable agriculture is knowledge intensive and uses few external inputs⁴⁴. Not all sustainable agriculture in developing countries is organic, and organic is not always sustainable. Conservation agriculture is one type of intensive sustainable agriculture that contributes to economic, environmental and social sustainability for smallholders in the face of degraded soils, declining availability of water and increasing energy costs⁴⁵. Conservation agriculture systems for smallholders are best developed *in situ* through a multi-stakeholder adaptive learning process^{46,47}. As with all systems agriculture, key principles are used to create a balanced system, rather than simply substituting one input for another, such as an improved seed or a different kind of, or more, fertilizer. A systems approach could include improved seed and selective fertilizer use (such as a teaspoon of fertilizer on each plant once it has emerged), but the interactions between the practices and biophysical and social context must be carefully monitored and adapted.

Pretty et al.⁴⁸ sought to determine which low-cost and locally available technologies and inputs increased total food crop productivity and the impact of these methods on water use efficiency, carbon sequestration and pesticide use. They analyzed over 286 agricultural projects covering 37 million hectares in 57 developing countries that used a variety of sustainable farming technologies and practices. They found that 12.6 million farmers on 37 million hectares were engaged in transitions toward agricultural sustainability. When agricultural practices that could improve sustainability were adopted, average crop yields and available food, over a variety of systems and crops, increased by 79%.

These practices included better use of locally available natural resources, such as conservation agriculture, water harvesting, use of compost and livestock manures, irrigation scheduling and management, intensification of microenvironments in farm systems, such as gardens, orchards and ponds; managing diversity by adding new regenerative components, such as cover crops and green manures; better use of non-renewable inputs and external

technologies such as resistant crop varieties and improved livestock breeds, new seed, low-dose and non-toxic pesticide sprays, appropriately sized machinery; farmer and community participatory processes; building of human capital through continuous education; access to markets and infrastructure; and access to affordable and accessible finance. Three types of technological improvements were thought to have played substantial roles in the yield increases: more efficient water use in both dryland and irrigated farming; improvements in organic matter accumulation in soils and carbon sequestration; and pest, weed and disease control emphasizing in-field biodiversity and reduced pesticide use. Using a combination of different improvements and practices showed the greatest results.

Conservation agriculture utilizes all three types of technological improvements. The three principles for conservation agriculture, as developed by the International Center for Corn and Wheat Research (CIMMYT), the International Center for Tropical Agriculture (CIAT) and other centers of the Consultative Group on International Agricultural Research (CGIAR) are:

1. maintain, to the extent that local conditions allow, a year-round cover over the soil provided by the current crop, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop;
2. minimize soil disturbance by tillage, eliminating tillage altogether once the soil has been brought to good condition;
3. diversify crop rotations, sequences and combinations, adapted to local socio-economic and environmental conditions, which contribute to maintaining biodiversity above and in the soil, and help avoid build-up of pest populations within the spectrum of soil inhabitants⁴⁹.

The advantages of conservation agriculture over conventional tillage systems are expected to grow as fresh water becomes scarcer in irrigated systems, as volatility increases in rainfed systems and as climate change intensifies⁵⁰. Efforts by NGOs and the CGIAR system to adapt conservation agriculture techniques to the systems of smallholders, enhances future food security.

IAASTD⁵¹ and Pretty⁵² both recommend that priority be given to developing technologies that follow the general principles of sustainable agriculture by focusing on integrating biological and ecological processes (such as nutrient cycling, nitrogen fixation, soil regeneration and biodiversity) into the production processes; minimizing use of non-renewable inputs that cause harm to the environment or to the health of farmers and consumers; and make productive use of the knowledge and skills of farmers, and people's collective capacities to work together to solve common problems. The idea of agricultural sustainability does not mean ruling out any technologies or practices on ideological grounds if a technology does not cause undue harm to the environment. For example, integrated soil fertility management can benefit from the judicious use of inorganic fertilizer combined with 'organic' fertilizers,

Table 1. Key events/documents in seeking food security and sustainability in developing countries.

Event	Year	Sponsorship	References
Rome Declaration of Food Security	1996	Food and Agriculture Organization of the United Nations	2
Millennium Declaration, including the Millennium Development Goals (MDGs)	2000	United Nations	3
New Partnership for Agricultural Development (NEPAD)	2001	African Union	4
Comprehensive Africa Agricultural Development Programme (CAADP)	2002	New Partnership for African Development (African Union)	5
G8 Africa Action Plan	2002	G8 nations	7
Presidential Initiative to End Hunger in Africa	2002	United States Department of State	9
World Summit on Sustainable Development (WSSD)—International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) initiated	2002	FAO and World Bank	11
IAASTD Intergovernmental Plenary	2004	UN member states	12
Sirte Declaration on the Challenges of Implementing Integrated and Sustainable Development on Agriculture and Water in Africa	2004	African Union	6
Call for a uniquely African Green Revolution	2004	Kofi Annan, UN Secretary General	10
Approval of IAASTD principles and procedures	2005	IAASTD Governing Board [geographically balanced multistakeholder entity with 30 government and 30 civil society representatives (NGOs, producer and consumer groups, private sector entities and international organizations)]	13
Millennium Villages Project	2006	Earth Institute, Columbia University/UNDP	16,56
African Fertilizer Summit	2006	Africa Union	32
Alliance for a Green Revolution in Africa (AGRA)	2006	Bill and Melinda Gates Foundation (BMGF) and the Rockefeller Foundation (RF)	35,36
Approval of IAASTD Final Report	2008	Majority of participating governments and institutions	14
World Development Report: Agriculture for Development	2008	World Bank	16
L'Aquila Food Security Initiative	2008	G-8 Group	19
Conference on Trade and Development (UNCTAD)	2009	United Nations	36
World Food Security Summit	2009	United Nations	20
Partnering for Food Security	2009	US Department of State	21

which together are highly synergistic, as organic matter increases the water-holding capacity of soils and increases the efficiency of fertilizer use by crops⁵³.

In October 2009, the Royal Society of London published a call for increased UK investment in 'intensive sustainable agriculture'. In particular, they called for investment in ecosystem-based approaches. They see the need to link genomic research with ecosystem research.

Science can potentially continue to provide dramatic improvements to crop production, but it must do so sustainably. Science and technology must therefore be understood in their broader social, economic and environmental contexts. The sustainable intensification of crop production requires a clear definition of agricultural sustainability. Improvements to food crop production should aim to reduce rather than exacerbate global inequalities if they are to contribute to economic development⁵⁴.

The Royal Academy, like IAASTD, finds sustainable agriculture an important approach to increasing community

food security, particularly in Africa. A mixed model of technology and trade developed within a systems framework shows the promise for sustainable food security in developing countries. That approach is not a tech-fix approach, and requires substantial organizing at different levels and across levels. But in the long term, such investments will become self-sustaining in terms of rural and urban populations able to respond to global economic and climate shocks as access to natural resources becomes more constrained. All the approaches described require increased investment in agricultural research and outreach⁵⁵. The difference in approaches lies with the degree of local involvement in system design and implementation so that the producers of food have the capacity to continually adapt to changing resource constraints. The Millennium Villages Project⁵⁶ is an example of integrated approaches, attempting to judiciously utilize outside inputs with systems adaptations to increase village well-being as well as agricultural productivity.

Conclusions

Concern with equity requires intensive sustainable agricultural approaches that are inclusive of smallholders, ethnic minorities and women. Increasing depletion of energy and other natural resources makes attention to sustainable agriculture essential for the future in developing countries.

Developing countries, including sub-Saharan Africa, suffer disproportionately from climate change and the resulting scarcity of water. Further, deteriorating soils and rapid extraction of minerals, including petroleum, has increased national income but decreased food security³⁴. Trade and emergency food assistance have limitations as a tool for sustainable food security, particularly as the costs of raw materials, particularly petroleum, increase. Further, the volatility of market prices, as demonstrated by the extreme price changes in 2008, increase food insecurity for the most vulnerable.

Technologies need to be developed by African scientists related to specific African contexts. The success of the first Green Revolution, based on breeding for high response to inputs (water, fertilizer and infrastructure to provide it) cannot be replicated as these resources become scarcer and more expensive. While breeding, including using biotechnology, to overcome specific contextual restraints of drought and salinity, breeding for generalized pest resistance can serve to require ever-more numerous chemical fixes as pests evolve to survive embedded pesticides.

For this to happen, Staatz and Dembélé⁵⁷ call for a reversal in the massive underinvestment and significant mis-investment that has taken place in the past in African agriculture, which has led to a huge cost in forgone development for Africans. Such investments must be multigenerational and contextual, based on the wide range of ecosystems and cultures in sub-Saharan agriculture. The principles of sustainable agriculture should lead the research agenda. Collaborative approaches that include farmers, outreach workers and researchers will be locality specific. But the upfront costs of building that capacity will pay off in adaptive systems management in response to resource scarcity. Conservation agriculture and its attention to soil quality and crop rotation is a promising systems approach that builds on local knowledge and carefully chosen external inputs. A balance between producing for growing African urban populations and the livelihood strategies of rural people must be negotiated. A transparent system of research, outreach and learning is critical.

References

- 1 Flora, C.B. 1990. Rural peoples in a global economy. *Rural Sociology* 55(2):157–177.
- 2 FAO. 1996. Rome Declaration on World Food Security. Food and Agriculture Organization of the United Nations, Rome, Italy.
- 3 UNDP (United Nations Development Program). 2000. The UN and the MDGs: A Core Strategy. Available at Web site http://www.undp.org/mdg/core_strategy.pdf (verified 9 January 2010).
- 4 New Partnership for Africa's Development October 2001 Framework. Available at Web site <http://www.nepad.org/home/lang/en> (verified 15 March 2010).
- 5 Comprehensive Africa Agriculture Development Programme, FAO Corporate Document Repository, November 2002. Available at Web site <http://www.fao.org/docrep/005/y6831e/y6831e00.HTM> (verified 12 February 2010).
- 6 African Union. 2004. Sirte Declaration on the Challenges of Implementing Integrated and Sustainable Development on Agriculture and Water in Africa. Assembly of the African Union, 27 February, Sirte, Libya.
- 7 G8 Africa Action Plan G8 Information Center Delegations and Documents, 27 June 2002. Available at Web site <http://C:/Documents%20and%20Settings/cflora/Desktop/Food%20security/africaplan.html> (verified 12 February 2010).
- 8 2002 Kananaskis Interim Compliance Report Africa—Peer Review. Available at Web site <http://www.g7.utoronto.ca/summit/2002kananaskis/africaplan.html> (verified 11 February 2010).
- 9 USAID (United States Agency for International Development). 2007. President's Initiative to End Hunger in Africa: Partnering to Promote Agricultural Growth and Food Security (IEHA). US Agency for International Development, Washington, DC.
- 10 United Nations Press Release SG/SM/9405 AFR/988 6 July 2004. Secretary-General Calls for 'Uniquely African Green Revolution in the 21st Century'. Available at Web site <http://www.un.org/News/Press/docs/2004/sgsm9405.doc.htm>
- 11 United Nations. 2002. World Summit on Sustainable Development. Available at Web site <http://www.un.org/jsummit> (verified 12 February 2010).
- 12 IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2007. Agriculture at the Crossroads: Global Report. Island Press, Washington, DC. Available at Web site http://www.agassessment.org/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20Report%20%28English%29.pdf (verified 13 January 2010).
- 13 IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2005. Available at Web site <http://www.agassessment.org/index.cfm?Page=Overview&ItemID=3> (verified 13 January 2010).
- 14 IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2007. Agriculture at the Crossroads: Global Report. Island Press, Washington, DC. Available at Web site http://www.agassessment.org/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20Report%20%28English%29.pdf (verified 13 January 2010).
- 15 Kiers, E.T., Leakey, R.R.B., Izac, A., MHeinemann, J.A., Rosenthal, E., Nathan, D., and Jiggins, J. 2008. Agriculture at the crossroads. *Science* 320:320–321.
- 16 World Bank. 2008. World Development Report: Agriculture for Development. World Bank, Washington, DC. Available at Web site <http://siteresources.worldbank.org/INTWDR2008/Resources/2795087-1192111580172/WDROver2008-ENG.pdf> (verified 7 February 2010).
- 17 Pérez, M., Schlesinger, S., and Wise, T.A. with the Working Group on Development and Environment in the Americas. 2008. The Promise and the Perils of Agricultural Trade

- Liberalization: Lessons from Latin America. Washington Office on Latin America, Washington, DC. Available at Web site <http://ase.tufts.edu/gdae/Pubs/rp/AgricWGReportJuly08.pdf> (verified 9 January 2010).
- 18 Magdoff, F. and Tokar, B. 2009. Agriculture and food in crisis: an overview. *Monthly Review* 61(3):1–16.
 - 19 G8 Summit. 2009. L'Aquila Joint Statement on Global Food Security L'Aquila Food Security Initiative. Available at Web site http://www.g8italia2009.it/static/G8_Allegato/LAquila_Joint_Statement_on_Global_Food_Security%5B1%5D,0.pdf (verified 9 January 2010).
 - 20 FAO. 2009. The State of Food Insecurity in the World: Economic Crises – Impacts and Lessons Learned. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at Web site <http://www.fao.org/docrep/012/i0876e/i0876e00.htm> (verified 9 January 2010).
 - 21 US Department of State. 2009. Global Hunger and Food Security Initiative Consultation Document. Available at Web site <http://www.state.gov/s/globalfoodsecurity> (verified 13 January 2010).
 - 22 Mooney, P.H. and Hunt, S.A. 2009. Food security: the elaboration of contested claims to a consensus frame. *Rural Sociology* 74:467–497.
 - 23 Moore, K. (ed.). 2009. *The Sciences and Art of Adaptive Management: Innovating for Sustainable Agriculture and Natural Resource Management*. Soil and Water Conservation Society, Akeny, IA.
 - 24 UN (United Nations). 2008. Millennium Development Goals Report 2008. UNDP, New York, NY. Available at Web site http://www.undp.org/publications/MDG_Report_2008_En.pdf (verified 13 January 2010).
 - 25 US Department of State. 2009. Global Hunger and Food Security Initiative Consultation Document. Available at Web site <http://www.state.gov/s/globalfoodsecurity> (verified 13 January 2010).
 - 26 Mkandawire, R. 2009. The Global Partnership for Agriculture and Food Security: A Perspective from NEPAD/CAADP and the Potential Way Forward. Available at Web site <http://www.caadp.net/pdf/GPAFS%20brief%20to%20high%20level%20meeting.pdf> (verified 15 March 2010).
 - 27 FAO. 1996. Rome Declaration on World Food Security. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at Web site <file:///C:/Documents and Settings/cflora/Desktop/Foodsecurity/Rome Declaration on World Food Security.htm>
 - 28 US Department of State. 2009. Partnering For Food Security: Moving Forward. Available at Web site <http://www.state.gov/s/globalfoodsecurity/129626.htm> (verified 13 February 2010).
 - 29 New York Times, 2 December, 2007. Ending Famine, Simply by Ignoring the Experts. Available at Web site <http://www.nytimes.com/2007/12/02/world/africa/02malawi.html> (verified 13 February 2010).
 - 30 Afron News/The Chronical (Malawi), 7 February, 2010. Malawi's subsidized fertilizer smuggled and embezzled. Available at Web site <http://www.afrol.com/articles/17989> (verified 15 March 2010).
 - 31 Ricker-Gilbert, J., Jayne, T.C., and Black, J.R. 2009. Does subsidizing fertilizer increase yields? Evidence from Malawi. Paper provided by Agricultural and Applied Economics Association in its Series 2009 Annual Meeting, 26–28 July 2009, Milwaukee, Wisconsin with number 49532. Available at Web site <http://purl.umn.edu/49532> (verified 13 February 2010).
 - 32 Africa Fertilizer Summit 9–13 June 2006. Available at Web site <http://www.africafertilizersummit.org/> (verified 13 February 2010).
 - 33 Declaration of the World Summit on Food Security, Rome, 16–18 November 2009. <ftp://ftp.fao.org/docrep/fao/Meeting/018/k6050e.pdf> (verified 13 February 2010).
 - 34 The Millennium Promise; Millennium Villages Project. 2009. Improving Agriculture to Achieve the Millennium Development Goals: An interview with Dr. Pedro Sanchez. Available at Web site http://www.millenniumpromise.org/site/PageServer?pagename=mv_sanchez (verified 15 March 2010).
 - 35 AGRA. 2009. Available at Web site <http://www.agra-alliance.org> (verified 13 January 2010).
 - 36 AGRA. 2009. Lessons from the Global Food and Financial Crisis: Trade and Development to Unlock Growth in Africa's Breadbaskets. Available at Web site <http://www.agra-alliance.org/content/news/detail/962> (verified 13 January 2010).
 - 37 AGRA Press Release. 13 November 2009. Available at Web site <http://www.agra-alliance.org/content/news/detail/1086> (verified 13 February 2010).
 - 38 Brookes, G. and Barfoot, P. 2006. GM Crops: The First Ten Years: Global, Socio-economic and Environmental Impacts. Brief No. 36. ISAAA, Ithaca, New York.
 - 39 Ramaswami, B. and Pray, C.E. 2007. India: confronting the challenge—the potential of genetically modified crops for the poor. In S. Fukuda-Parr (ed.). *The Gene Revolution: GM Crops and Unequal Development*. Earthscan, London. p. 156–174.
 - 40 Wiggins, S. 2009. Can the small holder model deliver poverty reduction and food security for a rapidly growing population in Africa? Expert Meeting on How to feed the World in 2050, Food and Agriculture Organization of the United Nations, Economic and Social Development Department. p. 1. Available at Web site <ftp://ftp.fao.org/docrep/fao/012/ak982e/ak982e00.pdf> (verified 13 January 2010).
 - 41 Lamine, C. and Bellon, S. 2009. Conversion to organic farming: a multidimensional research object at the crossroads of agricultural and social sciences: a review. *Agronomy for Sustainable Development* 29:97–112.
 - 42 Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Aviles-Vazquez, K., Samulon, A., and Perfecto, I. 2007. Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems* 22(2):86–108.
 - 43 Rasul, G. and Thapa, G.P. 2003. Sustainability analysis of ecological and conventional agricultural systems in Bangladesh. *World Development* 31:1721–1741.
 - 44 Goldberger, J.R. 2008. Diffusion and adoption of non-certified organic agriculture: a case study from semi-arid Makueni District, Kenya. *Journal of Sustainable Agriculture* 32:531–564.
 - 45 Gowing, J.W. and Palmer, M. 2008. Sustainable agriculture development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. *Soil Use and Management* 24:92–99.
 - 46 Erenstein, O., Sayre, K., Wall, P., Dixon, J., and Hellin, J. 2007. Adapting no-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and subtropics. CIMMYT Working Paper.
 - 47 Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., and Damgaard-Larsen, S. 2009. Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. *Soil and Tillage Research* 103:23–32.

- 48 Pretty, J.N., Noble, A.D., Bossio, D., Dixon, J., Hine, R.E., Penning de Vries, F.W.T., and Morison, J.I.L. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology* 40:1114–1119.
- 49 FAO. 2008. Investing in Sustainable Agricultural Intensification: The Role of Conservation Agriculture, A Framework for Action. Food and Agriculture Organization of the United Nations, Rome, Italy.
- 50 Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., and Damgaard-Larsen, S. 2009. Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. *Soil and Tillage Research* 103:23–32.
- 51 Markwei, C., Nodlovu, L., Robinson, E., and Shar, W. 2008. International Assessment Agricultural Knowledge, Science and Technology for Development (IAASTD) Sub-Saharan Africa summary for decision makers. Available at Web site http://www.fanrpan.org/documents/d00522/IAASTD_summary_decision_makers.pdf (verified 15 March 2010).
- 52 Pretty, J. 2008. Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1491):447–465.
- 53 Toenniessen, G., Adesina, A., and DeVries, J. 2008. Building an alliance for a green revolution in Africa. *Annals of the New York Academy of Sciences* 1136(1):233–242.
- 54 Royal Society of London. 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. The Royal Society, London.
- 55 Fan, S. and Rosegrant, M.W. 2008. Investing in Agriculture to Overcome the World Food Crisis and Reduce Poverty and Hunger. IFPRI Policy Brief 3, Washington, DC. Available at Web site <http://www.ifpri.org/sites/default/files/publications/bp003.pdf> (verified 7 February 2010).
- 56 Buse, K., Ludi, E., and Vigneri, M. 2008. Sustaining and Scaling the Millennium Villages: Moving from Rural Investments to National Development Plans to Reach the MDGs Formative Review of MVP: Synthesis Report. Overseas Development Institute, London. Available at Web site http://www.millenniumvillages.org/docs/ODI_SynthesisReport_Sept23_2008.pdf (verified 15 March 2010).
- 57 Staatz, J.M. and Dembélé, N.N. 2007. Agriculture for Development in Sub-Saharan Africa. Background Paper for the World Development Report 2008. Available at Web site http://siteresources.worldbank.org/INTWDR2008/Resources/2795087-1191427986785/StaatzJ&DembeléN_AgriForDevInSSA_ve19.pdf (verified 13 February 2010).