Chapter 1

Key Development Challenges of a Fundamental Transformation of Agriculture

Lead Article: AGRICULTURE AT THE CROSSROADS: ASSURING FOOD SECURITY IN DEVELOPING COUNTRIES UNDER THE CHALLENGES OF GLOBAL WARMING

Ulrich Hoffmann
UNCTAD secretariat

Abstract

The problems of climate change, hunger and poverty, economic, social and gender inequity, poor health and nutrition, and environmental sustainability are inter-related and need to be solved by leveraging agriculture's multi-functionality. Against this background, a fundamental transformation towards climate-friendly agriculture, consisting of a mosaic of agro-ecological production practices, must become the new paradigm, but it should not compromise other very important development objectives:

- Addressing the equity challenge, notably food security and farmer livelihoods.
- Enhancing sustainable productivity, based on a new, systemically different definition that focuses on total farm output instead of productivity per unit of labour, and
- Strengthening resilience to resource and energy scarcity and climate change.

It is therefore important to think in systems, rather than overemphasizing a climate focus.

A. Introduction

Climate change (CC) has the potential to damage irreversibly the natural resource base on which agriculture depends, with grave consequences for food security. CC could also significantly constrain economic development in those developing countries that largely rely on agriculture (for more information, see Lim Li Ching, 2010). Therefore, meeting the dual challenge of achieving food security[1] and other developmental co-benefits, on the one hand, and mitigating and adapting to CC, on the other, requires political commitment at the highest level for a fundamental and urgent transformation of agriculture. In fact, time is getting the most important scarcity factor in dealing with CC (Hoffmann, 2011).

The UNCTAD Trade and Environment Review 2013 gives an opportunity to more than 50 experts to analyze various specific aspects of the fundamental transformation of agricultural production methods and systems required for dealing with the serious challenges emanating from global warming and the trade offs to be made in enhancing the mitigation and adaptation potential of agriculture as part and parcel of a pro-poor development approach in agriculture fully exploiting agriculture's multi-functionality.

B. Agriculture - a key driver and a major victim of global warming

As most of the greenhouse gases (GHG), with the exception of methane, have a half life of over a hundred years, global GHG emissions will have to peak by 2020 and drop by 75-80 per cent in the period to 2050 to limit global warming to 2 degrees (The Climate Group, 2008: 19).[2] Yet, total GHG emissions for 2010 are estimated to have increased by more than 6 per cent, a historical record (The Guardian, 2011; and IEA, 2011a: 7), followed by an estimated increase of 3.2 per cent in 2011.[3] Also, according to estimates of analysts at Pricewaterhouse Coopers (PwC), global carbon intensity (i.e. carbon emissions per unit of GDP) has increased for the first time in many years. "Instead of moving too slowly in the right direction, we are now moving in the wrong direction", said one of the PwC analysts. In principal, we follow the GHG emissions trends under the worst case scenario of the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) (Financial Times, 2011: 1).[4]

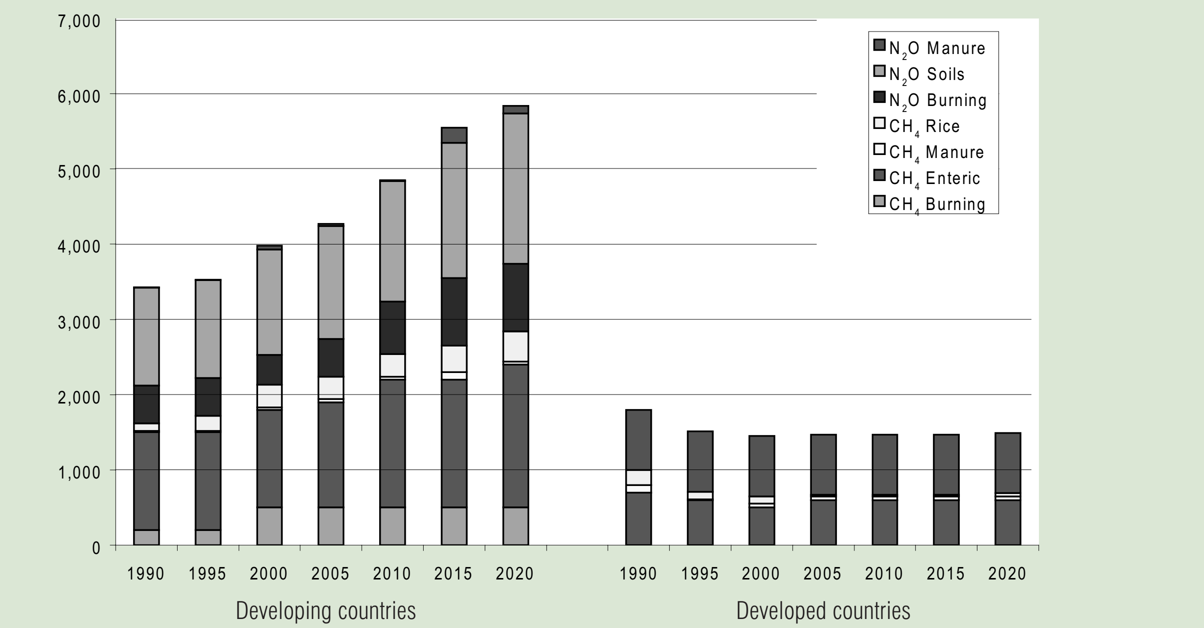
Agricultural emissions of methane (CH_4) and nitrous oxide (N_2O), which account for over 90 per cent of total agricultural GHG emissions, grew by 17 per cent in the period 1990–2005 (IPCC, 2007a: 499), roughly proportionate, for instance, to the increase in global cereals' production volume, but about three times as fast as productivity increased in global cereals' production.[5] These GHG emissions are predicted to rise by 35-60 per cent by 2030 in response to population growth and changing diets in developing countries, in particular towards greater consumption of ruminant meats and dairy products, as well as the further spread of industrial and factory farming, particularly in developing countries (IPCC, 2007a: 63). In other words, instead of cutting agricultural emissions by some 40 per cent by 2030, in reality we follow exactly the opposite trend.

As can be seen from figure 1, the recent and future rise in global agricultural GHG emissions is mainly occurring in developing countries. In 2005, the latter accounted for three quarters of nitrous oxide and methane emissions in the agricultural sector. These emissions are mainly caused by some 15-20 developing countries (see figure 2). The countries in figure 2 cause over 70 per cent of agricultural emissions worldwide. Although the least developed countries (LDCs) are not a significant contributor to global agricultural emissions, the latter account for the bulk of national GHG emissions (as can be seen in figure 3, in LDCs agriculture-related GHG emissions account for about 70 per cent of total GHG emissions).

Global warming is a threat multiplier, i.e. compounding, supplementing or reinforcing other threats so that the bio-physical vulnerability of agriculture increases. The main impact of global warming on agricultural production can be summarized as follows:[6]

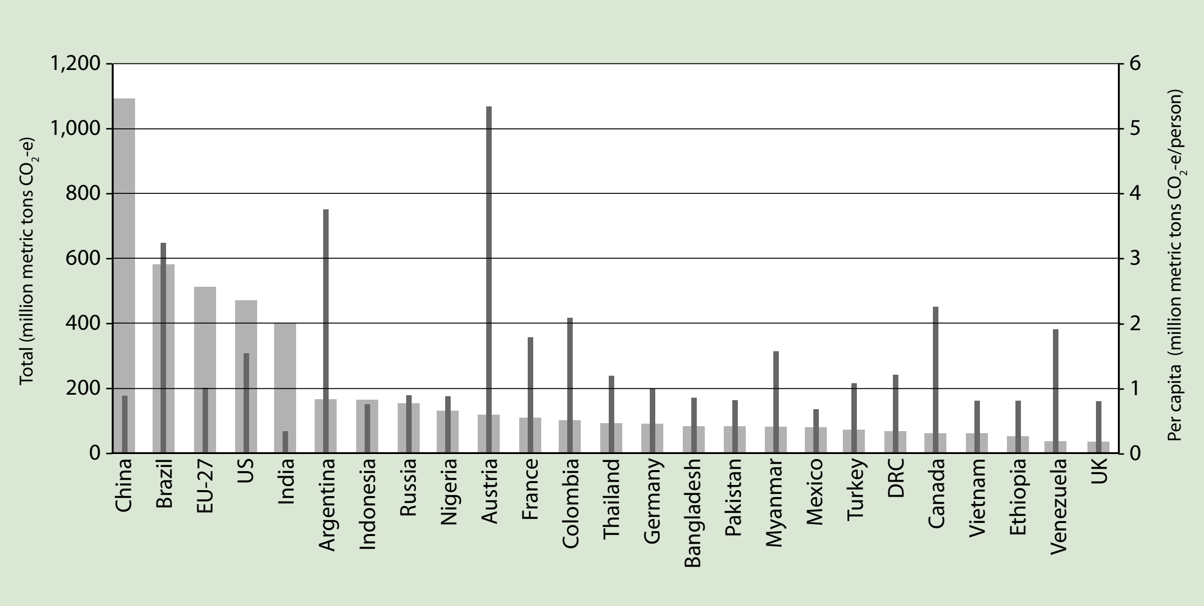
- Higher temperatures affect plant, animal and farmers' health,[7] enhance pests and reduce water supply increasing the risk of growing aridity and land degradation.
- Modified precipitation patterns will enhance water scarcity and associated drought stress for crops and alter irrigation water supplies. They also reduce the predictability for farmers' planning.
- The enhanced frequency of weather extremes

Figure 1: Estimated historical and projected nitrous oxide and methane emissions in the agricultural sector of developing and developed countries, 1990–2020, in thousand t CO_2-eq



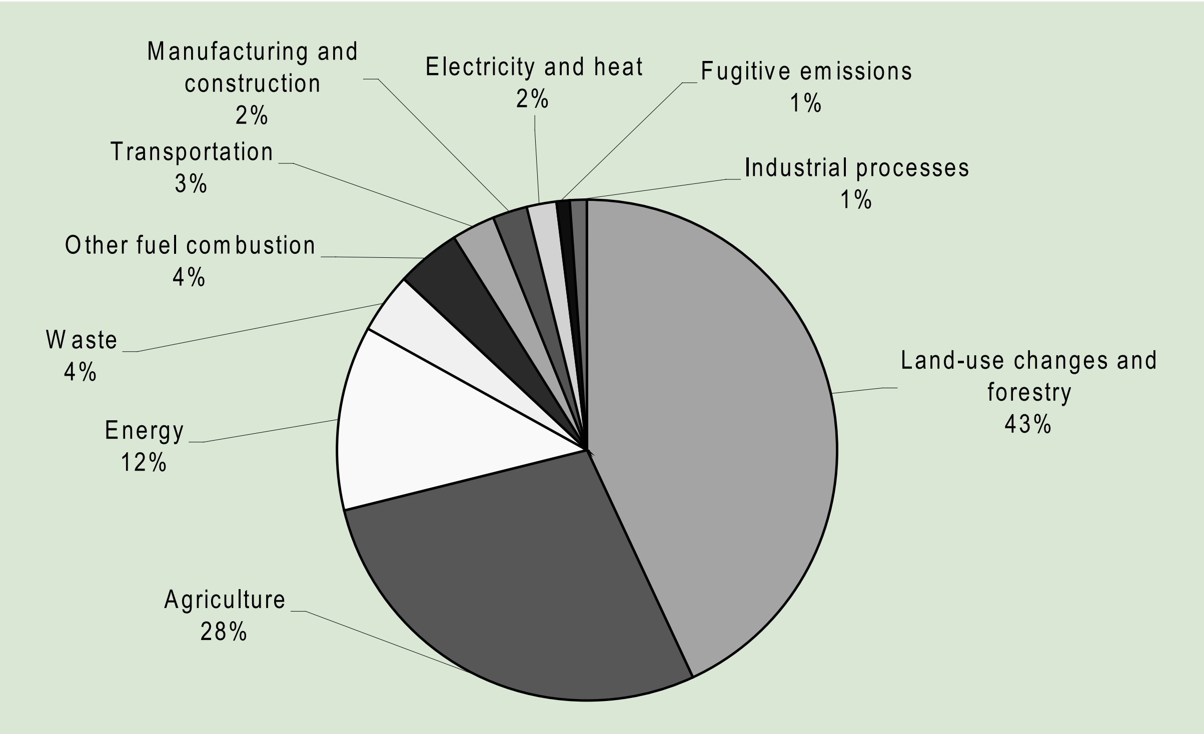
Source: IPCC (2007a: 504).

Figure 2: Top 25 GHG emitting countries from agriculture (total and per-capita emissions in CO_2-eq for the year 2000*)



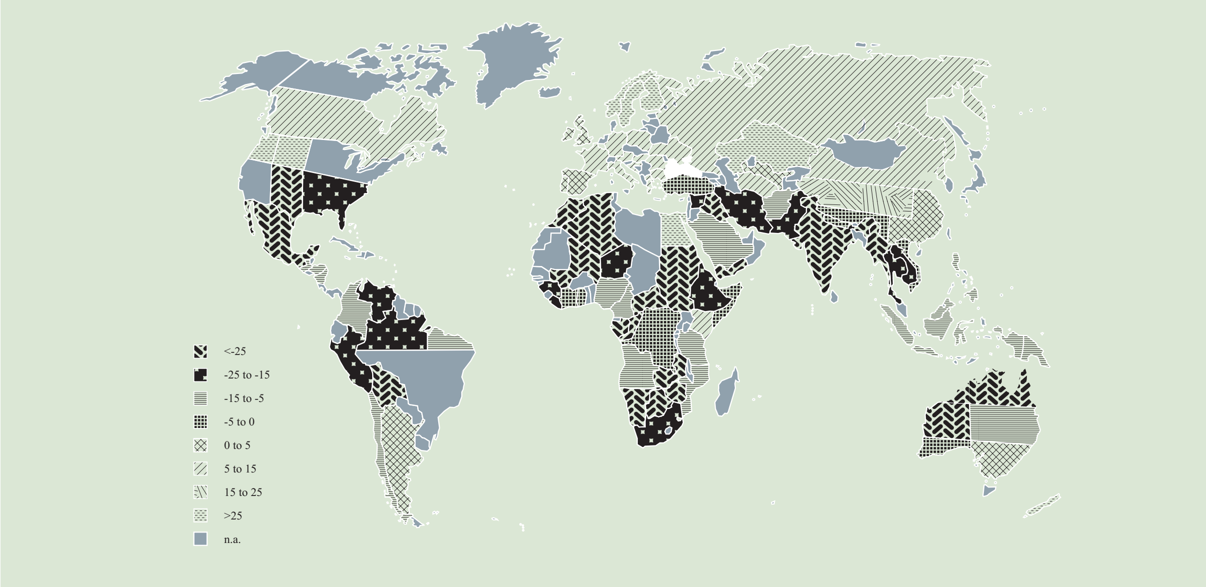
Source: World Resources Institute, quoted in Müller et al. (2011a).
Note: * CO_2 emissions are confined to fossil fuel combustion only.

Figure 3: LDC GHG emissions by sector, 2005 (per cent of total emissions)



Source: UNCTAD (2010: 127).

Figure 4: Projected climate-change-caused changes in agricultural productivity by 2080, incorporating the effect of carbon fertilisation



Source: Cline (2007) and Yohn et al. (2007).

may significantly influence both crop and livestock production.[8] It may also considerably impact or destroy physical infra-structure for agriculture.[9]

- Enhanced atmospheric concentrations of CO_2 may, for a limited period of time, lead to 'natural' carbon fertilization and thus a stimulus to crop productivity.[10]
- Higher temperatures go hand in hand with higher ozone concentrations. Ozone is harmful to all plants but soybeans, wheat, oats, green beans, peppers, and some types of cotton are particularly vulnerable (FAO, 2012a).
- Global warming will also negatively impact the nutritional quality[11] of some food, in particular the protein and micronutrients' content (for more information, see the comment of Högy and Fangmeier in this Chapter).[12]
- Higher temperatures are likely to increase the exposure of plants and animals to diseases and pests, thus increasing production and handling losses.[13]
- Sea level rise is likely to influence trade infra-structure for agriculture, may inundate producing areas and alter aquaculture production conditions.
- Global warming is not uniformly problematic. It will lead to improved crop productivity in parts of the tropical highlands and extend cropping periods or allow multiple harvests in temperate zones (FAO, 2012a).

The above-mentioned risks and stress factors act individually, but we will also see increasing stress combinations. There is a great deal that is as yet unknown about how such stresses may combine; therefore, more research on the interactions between different abiotic and biotic stresses in key agricultural systems is urgently required (FAO, 2012a). Furthermore, temperature increases are likely to have non-linear effects on yields and food quality.

Climate calamities are likely to hit the poor segments of the population and poor countries particularly hard as their adaptive capacity and resilience[14] is the lowest. Well-off segments of the population can 'buy' food security, at least in the short run (FAO, 2012a: 3).

The impact of global warming has significant consequences for agricultural production and trade of developing countries as well as an increased risk of hunger. Preliminary estimates for the period up to 2080 suggest a decline of some 15-30 per cent of agricultural productivity in the most climate-change-exposed developing-country regions - Africa, South Asia and Central America[15] (see figure 4).[16] For some countries in these regions, total agricultural production could decline by up to 50 per cent. According to FAO (2012a: 43), "in some locations, a combination of temperature and precipitation changes might result in complete loss of agricultural activity; in a few locations, agriculture might become impossible".[17]

The poorest farmers with little safeguards against climate calamities often live in areas prone to natural disasters. More frequent extreme events will create both a humanitarian and a food crisis (FAO, 2009a).

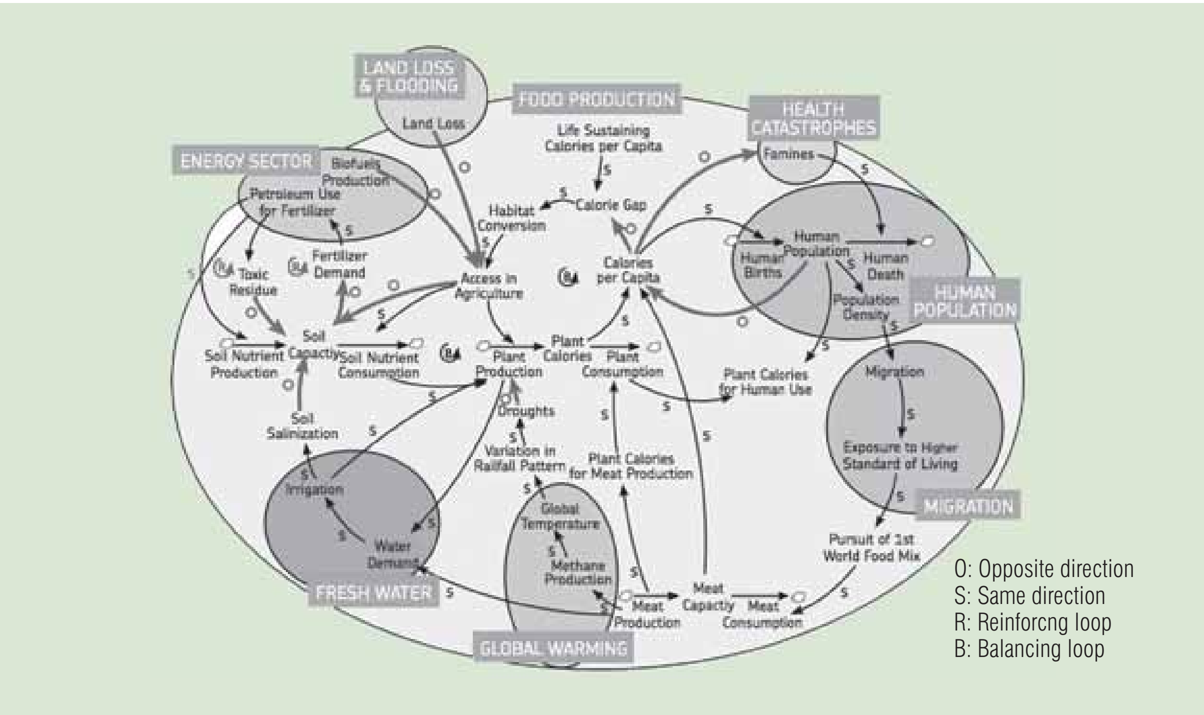
Agriculture provides essential nourishment for people and is the necessary basis for many economic activities. In a large number of developing countries, agriculture accounts for between 20-60% of GDP[18] and provides the livelihoods for approximately 2.6 billion people (i.e. some 40% of global population) (FAO, 2012a). What is more, according to De Janvry and Sadoulet (2009), agriculture-driven growth is three times more likely to reduce poverty than GDP growth in other sectors of the economy.

The current system of industrial agriculture, productive as it has been in recent decades, still leaves about 1 billion people undernourished[19] and poverty stricken, 70% of whom live in rural areas.[20] Millennium Development Goal (MDG) one aims at eradicating extreme hunger and poverty. One of the most effective ways of halving both the number of hungry and poor by 2015 is to take the necessary steps of transition towards more sustainable forms of agriculture that nourish the land and people and provide an opportunity for decent, financially rewarding and gender equal jobs. Meeting health targets from MDG 3 and 6 are also linked to major changes in agriculture, resulting in a more diverse, safe, nutritious and affordable diet. Therefore, the problems of climate change, hunger and poverty, economic, social and gender inequity, poor health and nutrition, and environmental sustainability are inter-related and need to be solved by leveraging agriculture's multi-functionality (Herren et al., 2011).

Against this background, climate-friendly agriculture must become the new paradigm, but it should not compromise other very important developmental objectives:

- Addressing the equity challenge, notably food security and farmer livelihoods.
- Enhancing sustainable productivity, based on a new, systemically different definition that focuses on total farm output instead of productivity per unit of labour.[21]
- Strengthening resilience to resource and energy scarcity and climate change, and
- Reflecting and capitalizing on the multi-functionality of agriculture.

Figure 5: Systemic embedding of climate-friendly agriculture



Source: Herren (2012).

It is therefore important to think in systems, rather than overemphasizing a climate focus (see figure 5).

C. Required fundamental transformation of agriculture

To understand the direction and structure of the required fundamental transformation, it is important to appreciate the patterns of the technical climate mitigation potential in agriculture. According to the fourth assessment report of IPCC (2007a: 515), 89 per cent of the technical mitigation potential is related to soil carbon sequestration, about 9 per cent linked to mitigation of methane and only about 2 per cent tied to mitigation of nitrous oxide emissions from soil (correlating with nitrogen fertilizer use). As the world currently follows the worst case scenario of GHG emissions projected by IPCC and IEA (i.e. implying a global warming of 4-6 degrees Celsius), climate resilience and adaptation, in combination with productivity increases, should be prioritized. In general, GHG emissions from agriculture can be reduced by change of production systems and management practices that in many cases also foster productivity and enhance resilience (FAO, 2012a).

Against this very background, the required transformation of agriculture needs to meet the following objectives and approaches, which are further elaborated on by the authors of this Review:[22]

- Increasing the soil carbon content, combined with closed nutrient cycles[23] and an integrated approach to agricultural production.[24]
- Reduction of direct and indirect (i.e. through the feed chain) GHG emissions of livestock production.
- Reduction of indirect (i.e. changes in land-use-induced) emissions through sustainable peatland, forest and grassland management.
- Optimization of organic and inorganic fertilizer use, including through closed nutrient cycles in agriculture.
- Reduction of waste throughout the food chains.
- Changing dietary patterns towards climate-friendly food consumption.
- Reform of the international trade regime for food and agricultural products.

In implementing the above-outlined elements of a fundamental transformation of agriculture, one should not overlook:

1. The interlinkages between the elements.
2. The merits and demerits of single climate-friendly practices versus those of systemic changes (through agro-ecology, agro-forestry, organic agriculture).
3. The need for a two-track approach:
   (i) reducing environmental impact of conventional agriculture; and
   (ii) broadening scope for and further developing agro-ecological production methods.

D. The paradigm shift has started, but is largely incomplete[25]

The food crisis of 2008 was an important catalyst for realizing the need for fundamental transformation and questioning some of the assumptions that had driven food and agricultural policy in recent decades. The crisis led to a reversal of the long-term neglect of agriculture as a vital economic sector. Also, the declining trend of public funding for agriculture was arrested and some new funding secured, which, however, is still much behind commitments and requirements. Some of the additional funding is now more open to country-led programs with strong state involvement. In this context, some of the additional funding goes to important areas, such as smallholder support, role of women in agriculture, the environmental crisis of agriculture, including climate change, and weakness of international markets.

However, we neither see the necessary level of urgency nor political willingness for drastic change. Priority remains heavily focused on increasing production (mostly under the slogan "more with less"). The currently pursued approach is still very much biased towards expansion of "somewhat-less-polluting" industrial agriculture, rather than more sustainable and affordable production methods. Also, the main problem of hunger is still not appreciated - access to affordable food in rural areas, the lack of means of production and access to resources for smallholders. One does still not recognize that a paradigm shift is required, resulting from (i) deepening integration of food, energy and financial markets; (ii) resource constraints / planetary boundaries; and (iii) the increasing risk caused by climate change. The current demand trends for biofuels, excessively meat-based diets and post-harvest food waste are regarded as given, rather than challenging their rational. There is also little recognition of the prevailing market power asymmetries in food input and output markets. Finally, there is too little and too late progress on restrictions and the development of regulation on land grabs.[26]

The still unresolved reform agenda items are:[27]

- Reduce fuel-intensive, external input-dependent agricultural production methods towards agro-ecological practices, recognizing the multi-functionality of agriculture.
- Discourage industrial livestock production and associated massive use of concentrate feed.
- Discourage expansion of biofuel production: discontinue blending quotas, reduce subsidies, revise trade restrictions.[28]
- Reduce financial speculation (i.e. financialization of food markets) and limit irresponsible land investments (see the commentary of Müller in Chapter 5).
- Reform global agricultural trade rules, giving greater policy space for assuring national food sovereignty, climate-change adaptation/resilience, rethink focus on integrating smallholders into global supply chains (see Chapter 5).
- Reduce food price volatility, without bedding exclusively on hedging options.[29]

In essence, as pointed out by Naerstad (2011: part II, p. 65), "a more radical transformation of agriculture is needed, one guided by the notion that ecological change in agriculture cannot be promoted without comparable changes in the social, political, cultural and economic arenas that also conform agriculture".

Commentary I: Agriculture: A Unique Sector in Economic, Ecological and Social Terms

Jean Feyder
Ambassador, Former Permanent Representative of Luxembourg to the UN and WTO in Geneva

Abstract

More than one billion people are suffering from hunger and malnutrition. Paradoxically, most of them are in rural areas, and only 20 per cent are in city slums, while a small minority are victims of war or civil conflict.

Low prices of food products produced by smallholder farmers can affect their incomes and contribute to poverty and hunger. Only stable and fair prices will give them indispensable buying power.

Adequate regulation of agricultural markets is needed to shield small producers from international competition and dumping of food imports.

Fast deteriorating ecosystems, climate change and water scarcity seriously threaten food security. These challenges can best be met through the adoption of agroecology, organic and other sustainable farming methods.

Agriculture has to be put at the heart of any poverty reduction strategy. It is a multidimensional sector directly linked to the fight against hunger and malnutrition and to food security. At the same time, it is strongly influenced by international trade, finance, development cooperation and, increasingly, it is affected by climate change and environmental degradation. This diversity of functions and activities requires that issues relating to agriculture be treated in a holistic manner, and that the challenge of policy coherence be tackled both at national and international levels (for more detail, see Feyder, 2010).

Hunger and malnutrition are the main causes of mortality in the world today. Each day, they kill about 25,000 people, mostly children. As a result, their right to life and their right to food are most flagrantly violated. The international community agreed to wage war on this scourge of humanity when Heads of State and Government adopted the Millennium Development Goals (MDGs). The first goal committed to halve by 2015 the proportion of the world's population suffering from hunger and malnutrition – some 840 million people.

However, 10 years later more than a billion people – one person in seven – are still suffering from hunger and malnutrition. This is undoubtedly one of the most lethal effects of the world food and financial crises, together with the economic recession of the past few years. These crises have reversed the former trend of a decreasing number of people suffering from hunger and malnutrition. But the FAO also stresses that this trend, observed before the crises, would not in fact have been sufficient to achieve the first of the Millennium Development Goals.

Paradoxically, most of the victims of hunger and malnutrition reside in rural areas. According to the FAO, 50 per cent of them are small peasants, 20 per cent are landless, 10 per cent are nomadic herdsmen or small fishermen and 20 per cent live in city slums. Only a small minority suffer because of war or civil conflict. And whereas in the EU the farming population constitutes only 5 per cent of the total population, it is about 50 per cent in China, 60 per cent in India and between 60 and 80 per cent in sub-Saharan Africa (Feyder, 2010: 16-17).

This rural social class is, above all, often a victim of marginalization and exclusion from its governing classes (political, economic and financial) as well as from the urban milieu where there is a concentration of power and knowledge, and therefore money, including funds for development. Often the urban and rural worlds are separated by a cultural abyss, with the former displaying indifference, incomprehension and contempt.

Hundreds of millions of small peasants, mainly women, cultivate an average of between one and two hectares of land – and often even less – with hoes and machetes, which are the only tools at their disposal. By contrast, a Western European farmer possesses an average holding of 40 hectares, cultivated with increasingly powerful tractors and other machinery, and employs large quantities of pesticides and fertilizers. This also explains the huge productivity gap in agriculture between industrialized countries and a number of emerging countries, such as Brazil, on the one hand, and the great majority of developing countries on the other.

The financialization of agriculture is becoming a major new risk. Land-grabbing often leads to the expulsion of vulnerable rural communities. Financial speculation on food commodities continues to be a major cause of the price surge and volatility witnessed over the past few years (UNCTAD, 2009; UNCTAD and Chamber of Labour, Vienna, 2011). This issue, quite rightly, has been at the top of the international agenda and in G-20 meetings.

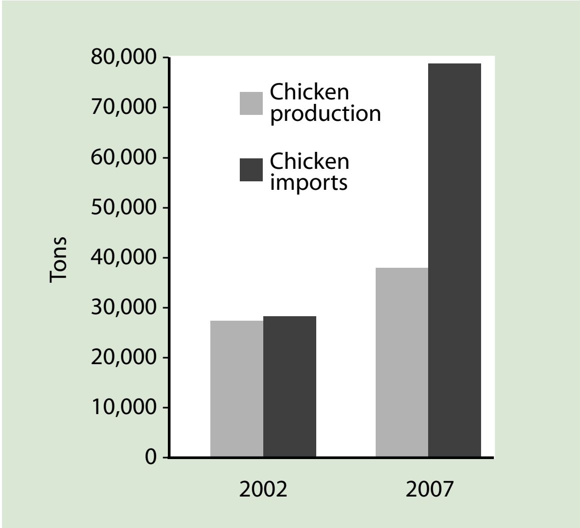
The production of agro-fuels takes more and more land away from food production. Yet, even though the use of these fuels contributes little – if at all – to reducing CO_2 emissions, their production continues to soar.

One of the main and more structural causes of the food crisis is disinvestment in agriculture, a sector that has long been neglected. Official development assistance to rural and agricultural development dropped from 18 per cent to 4 per cent between 1980 and 2004 (Feyder, 2010: 55).

Structural adjustment policies have led to massive trade liberalization and the opening up of markets, giving consumers access to cheap, imported food. Meanwhile, peasants have been encouraged to concentrate on producing export crops. However, the 2008 food crisis has radically challenged the relevance of this development model.

In the developing countries, especially the LDC's, imports of chicken, rice, tomato concentrate and milk powder have risen rapidly, ruining local production and the survival conditions of tens of millions of peasant families, not to mention the loss of jobs in the craft and industrial sectors, as they too have been unable to withstand international competition (figure 6 and 7). The trade balance in food products for least developed countries moved from a $1 billion surplus 30 years ago, to a deficit of $7 billion in 2000 and $25 billion in 2008 (Feyder, 2010: 72).

Figure 6: Ghana chicken production and importation, 2002-2007



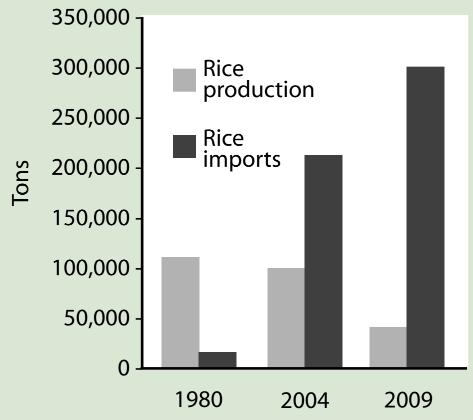
Source: FAOSTAT.

Thus, the dumping of food onto developing countries has penalized domestic producers who are forced to sell at reduced prices to fewer buyers. According to UNCTAD, the prices of food products and agricultural raw materials fell by 73 per cent and 60 per cent, respectively, between 1980 and 2003. In 2003, the price of coffee was only 17 per cent of what it had been in 1980, and that of cotton was 33 per cent (Nuri, 2005, p.352; see also FAO, 2011d, figure 20). But while producers in developed countries can usually call on their governments for compensation (which, for many, represents up to 60 per cent of their income), farmers in developing countries have no such recourse, and increasingly are unable to cover their costs. This dumping of cheap food onto developing countries has resulted in hunger for peasants and maintains them in poverty (Wise, 2010). As a result of this desperate situation, every year some 50 million people leave the rural areas in search of alternative livelihoods, leading to uncontrolled urbanization.

In the 1970s, Haiti was virtually self-sufficient in rice production, which is one of its main staple crops. However, as a consequence of its structural adjustment programme, the customs tariff, including on rice imported into Haiti, was reduced from 50 per cent to 3 per cent, making it the most "liberalized" country in the world! Today, less than 25 per cent of its rice needs are met by local production (figure 7).

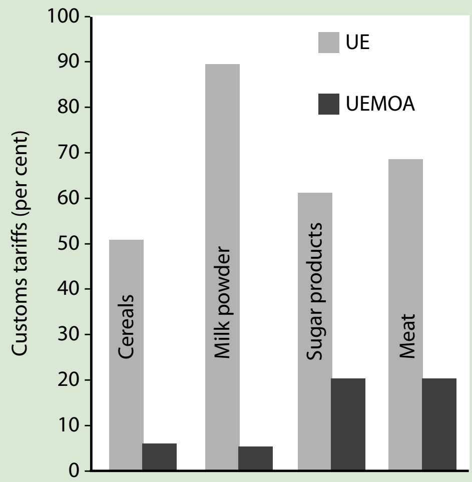
For years, in several United Nations bodies, including

Figure 7: Haïti: Rice production and imports, 1980, 2004, 2009



Source: FAOSTAT.

Figure 8: Custom tariffs in the EU and the Western African Economic and Monetary Union (UEMOA)



Source: Berthelot, 2008.

as Chair of UNCTAD's Trade and Development Board, I have been denouncing this negative impact on agricultural and industrial development in countries like Haiti. At the beginning of March 2010, former United States President Bill Clinton, who is currently the United Nations Secretary-General's Special Representative for Haiti, publicly acknowledged before a United States Senate committee that this policy, which he supported as former United States President, had been a mistake. He made a similar statement concerning agriculture in Africa when he said "we blew it". He went on to suggest we draw lessons from these errors and help countries like Haiti to find their way back to self-sufficiency in the food sector.

The solutions for feeding the growing world population and overcoming hunger and malnutrition are complex and must take into account the diversity and multi-functionality of agriculture, the specific conditions of each country, as well as climate change and increasing water scarcity. In developing their agricultural policy, governments should seek the active participation of farmers' associations.

Since 2008, various international conferences have been stressing the need for renewed investment in agriculture in order to relaunch agricultural production. More national and international funds are needed to help improve rural infrastructures and facilitate access to inputs, credit and knowledge. As the World Bank now argues, this would not only increase agricultural productivity but also reduce poverty three to four times more rapidly than in other sectors of the economy (World Bank, 2008:7). But the commitments made at the L'Aquila Summit of the G-8 in 2009 to reserve more than $20 billion over a three-year period for investment in agriculture are far from being fulfilled.

A policy of fair and stable prices is essential to enable peasants to emerge from poverty and to provide them with sufficient buying power. This also requires adequate regulation of agricultural markets so as to shield vulnerable agricultural producers against dumping and price volatility. In particular, such regulation should protect agricultural markets in developing countries and especially in the LDCs and provide for the setting up of properly managed marketing boards as well as a network of reserve stocks at national and regional levels. It has to be noted that a number of industrialized countries and in particular the EU continue to apply customs tariffs for their most sensitive agricultural products (cereals, milk powder, meat and sugar products) at levels far beyond those applied by many developing countries and in particular LDCs (figure 8).

In order to introduce these changes, the concerned governments need to make maximum use of the flexibility between applied and bound rates offered under WTO rules. This approach has to be understood, accepted and even encouraged by all concerned parties, including the World Bank and the IMF as well as the industrialized countries, mindful of the conditions that led to their own development. Similarly, bilateral trade agreements with these countries should be based on the principle of non-reciprocity.

Many countries need to address the sensitive issue of agrarian reform, including access to land, as a necessary precondition for relaunching agriculture and achieving a substantial reduction in poverty, following the example of a number of East Asian countries. The State might guarantee the peasants access to land, but this does not necessarily involve giving ownership rights to individuals.

Ecosystems are deteriorating at an unprecedented rate, particularly the climate, water, biodiversity and fish resources. Suddenly, peasants worldwide have to realize, with unbelievable brutality, that the conditions in which they live and work are deteriorating fast: erosion is advancing and climate change is affecting cultivation conditions and harvests. As a result, food security, especially for the most vulnerable, is becoming more uncertain. The developing countries, and above all the poorest and the island countries, which are the least responsible for these changes, run the greatest risks. The high-yield model in industrialized countries is now being called into question. There are formidable challenges of adaptation, especially for peasants around the world. And it is becoming clear that small-scale agricultural units are best able to meet this challenge: agroecology, organic farming and some other sustainable production methods that are respectful of nature show the way towards producing more and better quality food, but with less inputs, which are mostly locally available and based on closed nutrient cycles.

Commentary II: Conceptual and Practical Aspects of Climate Change Mitigation Through Agriculture: Reducing Greenhouse Gas Emissions and Increasing Soil Carbon Sequestration

A. Müller and A. Gattinger
Research Institute of Organic Agriculture (FiBL), Switzerland

Abstract

Mitigation in agriculture needs to be based on two pillars:

- Technically, nitrogen inputs should be reduced, organic fertilizers should replace synthetic fertilizers and storage losses should be minimized. Integrated systems with closed, efficient nutrient cycles should be the order of the day in the future.
- Socially, food wastage should be minimized and meat consumption reduced.

In general, reducing GHG emissions and increasing sequestration in agriculture is no easy task, either conceptually or in practice. But there are at least five clear exceptions plus one possible exception at the conceptual level.

First, avoiding open burning of biomass reduces emissions. Given that open biomass burning is the third largest contributor of direct GHG emissions from agriculture – accounting for more than 10 per cent – after nitrous oxide emitted from fertilized soils and methane from enteric fermentation in ruminants, there is a considerable and undoubted mitigation potential linked to this (Smith et al., 2007b; Bellarby et al., 2008). In most industrialized countries, open burning of biomass is prohibited, but in developing countries it is still common practice.

Second, reducing the global numbers of ruminants would directly reduce the corresponding methane emissions that account for about 30 per cent of total direct GHG emissions from agriculture (Smith et al., 2007b; Bellarby et al., 2008). This is mainly an issue for industrialized livestock systems, and not for smallholders. Due to carbon sequestration in pastures, pastoral livestock systems can even be carbon-neutral if stocking rates are adequately low.

Third, 30–40 per cent of food is lost globally, mainly as a result of wastage in industrialized countries and by storage losses in developing countries. Avoiding losses and wastage would therefore reduce the output needed and the corresponding GHG emissions (Godfray et al., 2010). Given the magnitude of losses and wastage, reducing them is essential in any effective climate mitigation policy for agriculture.

Fourth, conversion of pastures and/or forests to agricultural land and of forests to pastures needs to be reduced, as this leads to high CO_2 emissions, of roughly the same order as total direct agricultural GHG emissions (Smith et al., 2007b; Bellarby et al., 2008). Insofar as such land-use change is due to animal husbandry and feedstuff production for ruminants, ideally this reduction should be combined with reduced animal numbers.

Finally, the mitigation potential of carbon sequestration in optimally managed agricultural soils should be exploited. This potential is of the same order of magnitude as total agricultural emissions (Smith et al., 2007a; Bellarby et al., 2008). Soil carbon losses can be reduced and sequestration increased by application of organic fertilizers, minimal soil disturbance and planting legume leys in crop rotations.

Conceptually, these five aspects are uncontested, but, regrettably, they are the only ones of such clarity and importance. Addressing the other most relevant emission sources in agriculture (e.g. nitrous oxide emissions from soils, methane from rice production, manure management) is often highly complex. There are indications that actions and strategies relating to each of the sources may reduce emissions, but the high degree of complexity and context dependency of the underlying processes and their interactions with other processes often hinder clear statements. For example, reduced nitrogen input tends to reduce nitrous oxide emissions, but considerations of other characteristics of a location and cropping system, such as temperature, humidity, soil type, crops and fertilizer types, may dominate; or reduced flooding of rice fields cuts methane emissions but tends to increase nitrous oxide emissions. Nevertheless, indications are strong enough to mention reduced nitrogen applications as a sixth realistic option: the right type, place, rate and timing of nitrogen fertilizer applications are important (for more details, see Müller et al., 2011a; Müller and Aubert, 2013).

Regarding emissions from energy use, agriculture plays a minor role: farm machinery accounts for only 3 per cent of direct agricultural GHG emissions, while efficiency improvements in irrigation would contribute somewhat more, as irrigation accounts for about 7 per cent of emissions (Bellarby et al., 2008). However, reduction of energy use along the agricultural value chain has undoubted mitigation potential. There are significant emissions from transport, processing and storage, all of which are attributed by emission inventories to sectors other than agriculture. Thus, increasing efficiency and reducing the amount of road and air transport would considerably reduce emissions from the food system (for more information on supply-chain-related GHG emissions, see comments by Rundgren, Krain, Linne, and Gaebler in this chapter).

Regarding transport, it is worth pointing out that there is significant misreporting of emissions in national GHG inventories, as imports are not accounted for. National boundaries are the basis for emissions accounting, and “grey” embedded emissions in imported production inputs and consumption goods are added to the balance of the countries of origin. This considerably distorts national emissions from the food systems of countries where imports and exports play a crucial role.

With these remarks, we hope to have offered some options at the conceptual level. At the practical level, there are some difficulties, but differentiating three phases helps. Practical implementation means offering incentives, and establishing monitoring and enforcement mechanisms.

Providing incentives and enforcement are a challenge in many respects, but monitoring is relatively easy for the five proposals outlined above: avoiding burning, reducing animal numbers, avoiding losses and waste, and preventing deforestation and land conversion. Monitoring soil carbon changes can be more demanding, but it is feasible. Given the necessity of fundamental changes in agricultural production in order to increase its sustainability, these five aspects need to play a central role in any mitigation policy for agriculture. In addition, reducing nitrogen inputs should be a key policy target, and changes in how emissions from imports and exports are accounted for are needed to enable unbiased and more accurate assessments of countries’ emissions.

We do not touch on enforcement here, but what follows are some remarks on actions that need to be taken to move towards a more sustainable agricultural system as outlined above.

First, open burning of agricultural waste should be prohibited, as has been implemented successfully by industrialized countries. Information and training, and if necessary, even some financial support should accompany such a ban. This will partly influence weed and pest management and alter some nutrient flows, though some additional investment or labour costs may accrue (e.g. in sugarcane without pre-harvest burning). The biomass not burned is a valuable resource, which can be used as source material for compost or mulch (i.e. as organic fertilizer) or for bioenergy production. Clearly, these alternative uses need to be supported by information and training, and perhaps also by investment support. There may be some options for obtaining financial assistance from the carbon markets (e.g. renewable energy or composting projects under the Clean Development Mechanisms).

Second, reduced animal numbers and land-use change can be addressed on the producers’ side through optimal stocking rates, efficient grassland management and pastoralism, forest protection and land-use legislation. An optimal combination of crop farming and animal husbandry produces the most efficient nutrient cycles. However, reducing animal numbers is usually not an issue for smallholders in developing countries, and animal husbandry is essential for their food security. Actions on the producers’ side would include making inputs more expensive and, correspondingly, increasing output prices, which to some extent would reduce demand. On the demand side, it is primarily an issue on a global scale, and concerns mainly more wealthy consumers, whose increasing demand for meat and dairy products needs to be discouraged. One possible way to reduce demand would be by imposing a “meat tax” (tied to the emissions from animals). It is, however, questionable whether price increases could be high enough to achieve the necessary reductions; there also needs to be a discussion of consumer behaviour, lifestyles and quality of life, and how these are linked to excessive consumption, and meat consumption in particular.

The third issue, closely related to the issue of food wastage, concerns consumer behaviour and perceptions of quality, freshness and needs, which are decisive in this respect. Making food more expensive (through internalization of all external costs) would help, but aspects of justice need to be kept in mind, as significant price increases affect the freedom of choice of less wealthy people much more than that of wealthy people. Thus, again, sustainable lifestyles need to become a major consideration in policy discussions (for a detailed discussion of these aspects, see the commentary of Reisch in this chapter).

The other aspect of wastage is storage losses in many developing countries. In these countries, investment in storage and processing facilities and information and training would greatly help. This should be of primary importance, as it would reduce the needed level and intensity of actions on the other aspects mentioned here. Each unit loss avoided reduces pressure on production. Thus it is less about additional money needed for these measures, than about a shift in focus on where to channel the money that already flows into agriculture and the food system (see the commentary of Parfitt and Barthel in this chapter).

Fourth, reduced nitrogen inputs can be achieved through regulation, following the example of the successful EU Nitrogen Directive. Taxing inputs is another option: a heavy carbon tax would serve a similar goal, due to the use of fossil fuel for synthetic fertilizer production. However, nitrogen regulation should go further than only input reduction. Closed nutrient cycles and increased use of organic fertilizers should be the final goal, as this would also have highly beneficial effects on soil carbon levels and the corresponding mitigation (see the commentary of Leu later in this chapter).

This is linked to efforts for increasing soil carbon sequestration. To achieve this, the necessary steps include abolishing subsidies for synthetic fertilizers and supporting organic fertilizers, reducing soil disturbance in tillage operations and planting legume leys in crop rotations. Support should consist of both investment support and extension services (e.g. for optimal composting and compost use). Additional benefits from higher soil carbon levels include improved soil structure, soil fertility and soil life, which contribute to water holding and retention capacity with corresponding positive effects on climate change adaptation (i.e. increased resistance to drought and extreme weather events).

Finally, embedded emissions need to be made visible. National GHG inventories should be amended to take into account imports and exports in order to obtain a full and more accurate picture of national emissions, and not overlook the responsibilities of consumers abroad.

Commentary III: The Potential of Sustainable Agriculture for Climate Change Adaptation

A. Müller and U. Niggli
Research Institute of Organic Agriculture (FiBL), Switzerland

Abstract

Adaptation in agriculture needs to be based on four pillars:

- Increasing soil fertility: this can be achieved by replacing synthetic fertilizers with organic fertilizers, and monocultures with diverse crop rotations.
- Increasing biodiversity through diverse measures such as crop rotations, use of local varieties, catch crops, hedges and other landscape elements. This applies to field, farm and landscape levels. In addition, the use of sustainable and especially organic crop protection will foster biodiversity of insects, weeds, earthworms and other organisms.
- Providing information and extension services to support sustainable agricultural practices and organic agriculture, agroecology and agroforestry.
- Creating a level playing field for sustainable agriculture at the global level. This involves abolishing distorting subsidies, such as for synthetic fertilizers, and internalization of external costs.

Organic agriculture is an ideal solution as it responds to the first three pillars. In addition, global policies, and trade and competition issues need separate attention.

Adapting agriculture to climate change is unavoidable. For adaptation (on the concept, see box 1) to succeed, it is necessary for farms to take concrete adaptation measures, but also general long-term societal actions are needed. Our comments here focus mainly on adaptation measures for farms.

An aspect often neglected in current discussions on adaptation in agriculture (discussed in detail in Müller, et al., 2012) is that adaptation strategies also need to offer farming families solutions outside agriculture if agricultural production becomes impossible for them. For example, drought resistant varieties and improved efficiency of water use would help adaptation, but in some cases water availability may become too low to continue with agriculture. In such situations, the key question is where agricultural production may be optimally located over the next few decades, where it may be better to abandon it, and which livelihood alternatives will be available.

There are five key impacts and characteristics of climate change in agriculture (e.g. Easterling et al., 2007; Meehl et al., 2007; Rosenzweig and Tubiello, 2007):

- Climate change impacts will vary considerably by region: some regions will be affected positively, and others negatively. However, changes in production conditions will occur everywhere, necessitating adaptation. Regions benefiting from the positive effects of climate change should be able to take full advantage of their changed circumstances.
- Water will become a key issue. In some regions there will be increased water scarcity and drought, while in others extreme precipitation, water logging and flooding will become more frequent.
- Pressure from weeds, pests and diseases will increase.
- Increasing numbers of extreme weather events (e.g. heat waves and heavy precipitation) will pose a further challenge to agricultural production.
- Risks in agricultural production will increase due partly to greater climate variability.

Adaptation in agriculture needs to reduce exposure to these impacts, as well as sensitivity and vulnerability to them. This can be achieved by adopting sustainable agricultural production systems, such as agroecology, agroforestry or organic agriculture (Milestad and

Box 1: The concept of adaptation

We use the three concepts of "exposure", "sensitivity" and "vulnerability" to frame adaptation in agriculture. "Exposure" describes the likelihood that a system will experience certain conditions, such as drought (e.g. Smit and Wandel, 2006). "Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change" (IPCC, 2007b). "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change" (IPCC, 2007b).

Darnhofer, 2003; Borron, 2006; Niggli, 2009; El-Hage Scialabba and Müller-Lindenlauf, 2010; Müller et al., 2012).

There are many reasons why sustainable agriculture is a system well suited to adaptation. First, traditionally it uses locally adapted varieties and cropping practices, and it can therefore better adjust to local variability of climate change impacts.

Second, it can respond to increased water stress by maintaining and increasing soil organic matter, as this increases the soil's water holding and retention capacity. Using organic fertilizers, such as compost, and adopting diverse crop sequences, in particular with legume leys, are important means of achieving this. These are core practices of sustainable agriculture, and of organic agriculture in particular, with its strong focus on soil fertility, soil quality and plant health. The higher biodiversity in organic agriculture resulting from an optimal combination of crops with different needs also contributes to optimal water and nutrient use.

Third, high biodiversity also helps reduce the occurrence and severity of weeds and pest outbreaks, and plant and animal diseases (Smith et al., 2011; Niggli, 2009). In addition, complex crop rotations contribute to controlling pests more effectively as they break their life cycles. Improved soil fertility and plant health further reduce vulnerability to pressures from increased pests, weeds and diseases (Altieri, Ponti and Nicholls, 2005).

Fourth, improved soil quality and higher content of organic matter in the soil also reduce vulnerability to extreme events such as drought, flooding and water-logging, and erosion (Siegrist et al., 1998; Fliessbach et al., 2007; Niggli, 2009; El-Hage Scialabba and Müller-Lindenlauf, 2010). In addition, mulching and cover crops are common practices in sustainable agriculture, bare fallows are avoided and erosion is correspondingly reduced. Landscape elements such as hedges or agroforestry provide shelter and favourable microclimates, improving moisture management and capacity to adapt to high temperatures.

Fifth, the high biodiversity on sustainably managed farms (e.g. organic) also reduces the risk of total production losses due to climate change, and generally increases the resilience of agroecosystems (Altieri and Nicholls, 2006; Campbell et al., 2009). Through the combination of crop and livestock production as well as a larger number of crops grown, total economic failure can be avoided. Additionally, the economic risks are lower for organic farms, as they use fewer off-farm inputs and correspondingly incur lower upfront costs. Price premiums, for instance resulting from certified organic production, offer further potential for improving producers' economic situations. All these aspects combined provide inexpensive but effective risk management strategies, in particular insurance against crop failure (El-Hage Scialabba and Hattam, 2002; Eyhorn, 2007).

Agroecology, agroforestry and, in particular, organic agriculture thus reduce *vulnerability* through risk reduction based on diversification of livelihood strategies, cropping patterns and lower input costs. The focus on soil fertility, soil health and high biodiversity reduces *sensitivity*. This is of particular relevance for optimal water management and for optimal strategies to cope with pests and diseases. Reducing *exposure* is the most difficult, as this means shifting cropping locations or abandoning agriculture altogether in some circumstances.

How such fundamental changes can be supported, where necessary, needs further research. However, there are some readily available strategies that reduce vulnerability and sensitivity, as briefly described below.

First, soil fertility needs to be built up and soil degradation halted. For this, subsidies for synthetic fertilizers should be abandoned, where possible, without compromising food security. Where this is an issue, carefully designed transformation from synthetic to at least partly organic fertilizers, redesigned crop rotations with legumes and plants with different rooting depths, as well as closed nutrient cycles should be implemented. The simultaneous use of synthetic and organic fertilizers may not be advisable for climate change mitigation due to the resulting higher nitrous oxide emissions. However, particularly in a development context, adaptation in agriculture is key, and mitigation must never compromise on this.

Second, biodiversity needs to be enhanced. Local breeding programmes should be established or revitalized and supported, and farmers should be able to produce their own seeds. Practices such as agroforestry, and well-designed crop rotations need to be supported. Landscape elements also contribute to adaptation as they improve the microclimate. Payments for ecosystem services could be one type of financial incentive mechanism to encourage these practices.

This links to the third point: information and training are crucial for successful implementation of these adaptation strategies. Sustainable agricultural practices and organic agriculture, as a holistic agricultural production system, rely on the presence of a considerable body of knowledge.

Fourth, to be successful, adaptation strategies need to be accompanied by policy and trade measures. Massive trade distortions, such as the current subsidies for conventional production (e.g. cotton in the United States) need to be abolished. Similarly, the market power of agribusiness corporations in the seed markets and in plant protection is a hindrance that needs to be removed.

Finally, all external costs of agricultural production should be reflected in the price. Without this, conventional production will always have an unfair competitive advantage due to distorted production costs that do not include all the environmental and social costs of production. If those external costs were to be included in conventional production, it would prove to be more costly than sustainable agriculture.

Commentary IV: Food, Climate Change and Healthy Soils: The Forgotten Link

GRAIN

Abstract

Agriculture is starting to get more attention in international negotiations around climate change. The consensus is that it contributes 10–15 per cent of all global anthropogenic greenhouse gas (GHG) emissions, making it one of the key drivers of climate change. But looking at agriculture alone is not enough; it is also necessary to look at the larger food system. Beyond the emissions that occur on the farm, today's dominant industrial food system generates GHGs by transporting food around the world, by deforestation to make way for plantations and by generating waste. Pulling together the available data on these sources of emissions reveals that the global food system is responsible for around half of all global GHGs. Thus it is the food system as a whole which is at the centre of the problem of climate change.

If measures are taken to restructure agriculture and the larger food system based on food sovereignty, small-scale farming, agroecology and local markets, global GHG emissions could be cut by half within a few decades. There is no need for carbon markets or techno-fixes. What is needed are the right policies and programmes that bring about a shift from the current industrial food system to a sustainable, equitable and truly productive one.

A. Food and climate: piecing the puzzle together

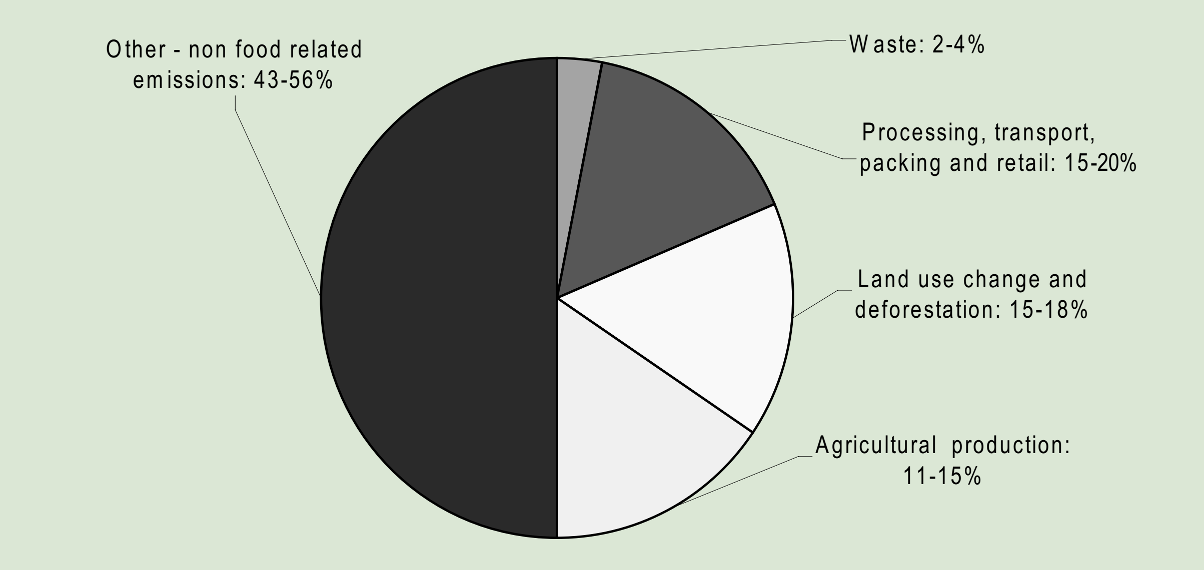
According to most studies, the contribution of agricultural emissions – the emissions produced on the farm – is between 11 and 15 per cent of all global emissions.[29] What often goes unsaid, however, is that most of these emissions are generated by industrial farming practices that rely on chemical (nitrogen) fertilizers, heavy machinery run on petrol, and highly concentrated industrial livestock operations that pump out methane.

The data for agriculture's contribution also often neglect to take into account the contribution of land-use changes and deforestation, which are responsible for nearly a fifth of global GHG emissions (WRI, undated; IPCC, 2004). Worldwide, agriculture is pushing into savannahs, wetlands, *cerrados* and forests, and is ploughing huge amounts of land. The expansion of the agricultural frontier is the dominant contributor to deforestation, accounting for 70–90 per cent of global deforestation (FAO, 2008; Kanninen et al., 2007). This means that some 15–18 per cent of global GHG emissions are produced by land-use change and deforestation for agriculture. And here too, the global food system and the industrial model of agriculture are the chief culprits. The main driver of this deforestation is the expansion of industrial plantations for the production of commodities such as soy, sugarcane, oil palm, maize and rapeseed. Since 1990, the area planted with these five commodity crops grew enormously, by 38 per cent (GRAIN, 2010).

These emissions from agriculture account for only a portion of the food system's overall contribution to climate change. Equally important are the emissions caused all along the chain, from when the produce leaves the farm until it is consumed.

Food production is the world's largest economic activity, involving more transactions and employing more people by far than any other sector. Today, food is prepared and distributed using enormous amounts of processing, packaging and transportation, all of which generate GHG emissions, although data on such emissions are hard to find. Studies looking at the EU conclude that about one quarter of overall transportation involves commercial food transport (Eurostat, 2011). Scattered figures on transportation available for other countries, such as Kenya and Zimbabwe, indicate that the percentage is even higher in non-industrialized countries, where "food production and delivery accounts for 60-80% of the total energy – human plus animal plus fuel – used" (Karekezi and Lazarus, 1995). With transportation

Figure 9: Contribution of the global food production system to total GHG emissions



Source: Estimates of GRAIN

accounting for 25 per cent of global GHG emissions, EU data enable an estimate – albeit a conservative one – for the contribution of the transport of food to GHG emissions of at least 6 per cent. Similarly, EU data derived from studies on processing and packaging of food within the EU show that these activities account for 10–11 per cent of GHG emissions (Bolla and Pendolovska, 2011), while refrigeration of food accounts for 3–4 per cent of total emissions (Garnett and Jackson, 2007), and food retail for another 2 per cent (Tassou et al., 2011; Venkat, 2011; Bakas, 2010). Based on the data for the EU, and extrapolating from the scarce figures that exist for other countries, we can estimate, conservatively, that at least 5–6 per cent of emissions result from food transport, 8–10 per cent from food processing and packaging, 1–2 per cent from refrigeration and another 1–2 per cent from retail. This amounts to a total contribution of 15–20 per cent of global emissions from all these activities.

Not all of what the food system produces gets consumed. The industrial food system discards up to *half* of all the food that it produces in its journey from farms to traders, to food processors, to stores and supermarkets. This is enough to feed the world's hungry six times over (Stuart, 2009). Much of this waste rots on garbage heaps and landfills, producing substantial amounts of GHGs. Different studies indicate that between 3.5 and 4.5 per cent of global GHG emissions come from waste, and that over 90 per cent of them come from materials originating in agriculture and its processing (Bogner et al., 2008). This means that the decomposition of organic waste originating in food and agriculture is responsible for 3–4 per cent of global GHG emissions.

Considering all these factors, it would appear that the current global food system, propelled by an increasingly powerful transnational food industry, is responsible for around half of all anthropogenic GHG emissions – between a low of 44 per cent and a high of 57 per cent.

B. Turning the food system upside down

Clearly, we will not resolve the climate crisis if the global food system is not urgently and dramatically transformed. The place to start is with the soil. Food production begins and ends with soil. It grows out of the soil and eventually goes back into it to enable more food to be produced. This is the very cycle of life. But in recent years humans have ignored this vital cycle: we have been taking from the soil without giving back.

The industrialization of agriculture, which started in Europe and North America and was later replicated in the Green Revolution that took place in other parts of the world, was based on the assumption that soil fertility could be maintained and increased through the use of chemical fertilizers. Little attention was paid to the importance of organic matter in the soil.

A wide range of scientific reports indicate that cultivated soils have lost 30 to 75 per cent of their organic matter during the twentieth century, while soils under pastures and prairies have typically lost up to 50 per cent. Without doubt, these losses have provoked a serious deterioration of soil fertility and productivity, as well as a higher risk exposure to droughts and floods.

Taking as a basis some of the most conservative figures provided by the scientific literature, the global accumulated loss of soil organic matter (SOM) over the past century can be estimated to be between 150 and 200 billion tons.[31] Not all this organic matter has ended up in the air as CO_2; significant amounts have been washed away by erosion and deposited at the bottom of rivers and oceans. However, it can be estimated that at least 200 to 300 billion tons of CO_2 have been released to the atmosphere due to the global destruction of soil organic matter. In other words, 25 to 40 per cent of the current excess of CO_2 in the atmosphere results from the destruction of soils and their organic matter.

There is some good news hidden in these devastating figures: the CO_2 that has been emitted into the atmosphere through soil depletion can be put back into the soil through a change in agricultural practices. There has to be a shift away from practices that destroy organic matter to ones that build up the organic matter in the soil. We know this can be done. Farmers around the world have been engaging in these very practices for generations. Research by GRAIN (2009) has shown that if the right policies and incentives were in place worldwide, soil organic matter contents could be restored to pre-industrial agricultural levels within a period of 50 years, which is roughly the same time frame that industrial agriculture took to reduce it. The continuing use of these practices would allow the offset of 24–30 per cent of current global annual GHG emissions.[32]

The new scenario would require a radical change in approach from the current industrial agriculture model. It would focus on the use of techniques such as diversified cropping systems, better integration between crop and animal production, and increased incorporation of trees and wild vegetation. Such an increase in diversity would, in turn, increase the production potential, and the incorporation of organic matter would progressively improve soil fertility, creating a virtuous cycle of higher productivity and greater availability of organic matter. The capacity of soil to hold water would increase, which would mean that excessive rainfall would lead to fewer, less intense floods and droughts. Soil erosion would become less of a problem, and soil acidity and alkalinity would fall progressively, reducing or eliminating the toxicity that has become a major problem in tropical and arid soils. Additionally, increased soil biological activity would protect plants against pests and diseases. Each one of these effects implies higher productivity and hence more organic matter available to soils, thus making possible higher targets for incorporation of soil organic matter over the years. More food would be produced in the process (see also the commentary of Leu on mitigating climate change with soil organic matter in organic production systems in this chapter).

This shift in agricultural practices would require building on the skills and experience of the world's small farmers, rather than undermining and forcing them off their lands, as is now the case. A global shift towards an agriculture that builds up organic matter in the soil would also contribute to removing some of the other major sources of GHGs from the food system. There are three other mutually reinforcing shifts that need to take place in the food system to support its overall contribution to climate change. The first is a shift to local markets and short circuits of food distribution, which would reduce transportation and the need for packaging, processing and refrigeration. The second is a reintegration of crop and animal production, which would also cut transportation, as well as the use of chemical fertilizers and the production of methane and nitrous oxide emissions generated by intensive meat and dairy operations. And the third is the stopping of land clearing and deforestation, which will require genuine agrarian reform and a reversal of the expansion of monoculture plantations for the production of agrofuels and animal feed. If the world becomes serious about undertaking these four shifts, it is quite possible for global GHG emissions to be cut by half within a few decades, and, in the process, this would go a long way towards resolving the other crises affecting the planet, such as poverty and hunger. There are no technical hurdles standing in the way; the world's farmers already possess the requisite knowledge and skills, and these can be further developed. The only hurdles are political, which is where we need to focus our efforts.

Commentary V: Mitigating Climate Change with Soil Organic Matter in Organic Production Systems

Andre Leu
President, International Federation of Organic Agricultural Movements (IFOAM)

Abstract

Past and present global efforts aimed at reducing carbon dioxide emissions by improving energy-use efficiency and the adoption of renewable energy sources have been unsuccessful. It is therefore critical to look at all readily available options that could significantly mitigate runaway climate change.

Sequestering CO_2 into the soil could bring about a significant reduction in GHG levels. There is scientific evidence that this can be achieved with current good organic agricultural practices and that the best organic farming practices can achieve even higher levels of CO_2 sequestration. Building up soil organic matter is one of the least costly climate change mitigation methods.

Helping farmers adopt these methods on a widespread basis would make a significant difference to the levels of CO_2 in the atmosphere and in the world's oceans. Importantly, this is not based on untested concepts such as carbon capture and storage; it is based on current practices that can be adopted by other land managers.

This could be financed through cap and trade systems that tax emissions. These taxes could then be used to pay farmers for their ecosystem services that fix the atmospheric CO_2 in the soil. Such a system could be either government administered or market-based.

A. Introduction

The world is failing to reduce GHG emissions despite commitments made under the Kyoto Protocol. According to the International Energy Agency (IEA, 2011b), energy-related CO_2 emissions reached a record high of 30.6 gigatonnes (Gt) in 2010 – a 5 per cent jump from the previous record in 2008. Moreover, the reduction in economic activity due to the global economic and financial crisis has not reduced the growth of GHG emissions.

While the first commitment period of the Kyoto Protocol and its Clean Development Mechanism (CDM) led to a small reduction in emissions by the Annex 1 parties to the Protocol, they failed to reduce the overall rate of global GHG emissions. The CDM has had very little impact because its complex rules make it difficult to achieve effective project results. A major issue has been GHG leakage (or rather outsourcing) from the Annex 1 countries to developing countries. Any small gains that have been achieved by the former in reducing GHG emissions have been more than lost by the polluting industries moving to developing countries and importing GHG-intensive products from there. The non-Annex 1 countries now account for the majority of the world's GHG emissions caused by expanding industries, deforestation, the burning of savannahs and the loss of soil carbon through poor agricultural practices.

The current state of the economies of developed countries, with their massive debts, means that they do not have the funds to shift significantly to the use of renewable energies and improve energy efficiency in the short term. Furthermore, the political climate has changed since the United Nations Climate Change Conference in Copenhagen in 2009, with very few governments willing to accept a slowdown in economic activity to meet emission reduction targets or to introduce major GHG reduction strategies.

The Cancun Climate Change Agreements mean that sequestration has to be part of any strategy mix to stabilize the level of atmospheric CO_2 (UNFCCC, 2011). This gas accounts for around 80 per cent of anthropogenic GHGs (WMO, 2011).

B. Soils as a carbon sink

Soils are the greatest carbon sink after the oceans. According to Professor Rattan Lal of Ohio State University, over 2,700 Gt of carbon is stored in soils worldwide. This is considerably more than the combined total of 780 Gt in the atmosphere and the 575 Gt in biomass (Lal, 2008).

The amount of CO_2 in the oceans is already causing a range of problems, particularly for species with calcium exoskeletons such as coral. Scientists are concerned that the increase in acidity caused by higher levels of CO_2 is damaging these species and threatens the future of marine ecosystems such as the Great Barrier Reef. The world's oceans, like the atmosphere, cannot absorb any more CO_2 without causing potentially serious environmental damage to many aquatic ecosystems (Hoegh-Guldberg et al., 2007).

Despite the fact that soil is the largest repository of carbon after the oceans and has the potential to sequester more CO_2 than biomass, neither soil nor agriculture is incorporated in any formal agreement of the United Nations Framework Convention on Climate Change (UNFCCC) or the CDM.

This needs to be changed because according to the Food and Agriculture Organization of the United Nations, "*Agriculture not only suffers the impacts of climate change, it is also responsible for 14 percent of global greenhouse gas emissions. But agriculture has the potential to be an important part of the solution, through mitigation — reducing and/or removing — a significant amount of global emissions. Some 70 percent of this mitigation potential could be realized in developing countries"* (FAO, 2012b).

C. Soil carbon sequestration through agricultural practices

The ability of soils to absorb enough CO_2 in order to stabilize current atmospheric CO_2 levels is a critical issue, and there is a major debate over whether this can be achieved through farming practices (Lal, 2007; Sanderman et al., 2010).

Two independent global meta reviews have looked at the average amount of CO_2 sequestered by organic farming systems.

A preliminary study by FiBL, published by FAO, collated 45 peer-reviewed comparison trials between organic and conventional systems that used 280 data sets (FAO, 2011b). These studies included data from grasslands, arable crops and permanent crops in several continents. A simple analysis of the data shows that, on average, the organic systems had higher levels of soil carbon sequestration (Gattinger et al., 2011).

Andreas Gattinger and colleagues observed (2011:16): *"In soils under organic management, the SOC* [soil organic carbon] *stocks averaged 37.4 tonnes C ha-1, in comparison to 26.7 tonnes C ha-1 under non-organic management."* This means that the average difference between the two management systems (organic and conventional) was 10.7 tonnes of carbon. Using the accepted formula that SOC x 3.67= CO_2 this means an average of more than 39.269 tonnes of CO_2 was sequestered in the organic system compared to the conventional system. The average duration of management of all included studies was 16.7 years (Gattinger et al, 2011). This means that an average of 2,351 kgs of CO_2 was sequestered per hectare every year in the organic system compared to the conventional system.

Another study by the United Kingdom Soil Association found that average organic farming practices removed about 2,200 kg of CO_2 per hectare per year (Azeez, 2009). This is critical information as it clearly shows that organic farmers are currently sequestering significant amounts of carbon. Most importantly, this is not based on untested concepts like "carbon capture and storage" and "clean coal"; it is based on current practices that can be adopted by other farmers.

D. Potential of organic practices

Based on these figures, the widespread adoption of current organic practices globally has the potential to sequester 10 Gt of CO_2, which is around 20 per cent of the world's current GHG emissions.

Grassland	3,356,940,000 ha
Arable crops	1,380,515,000 ha
Permanent crops	146,242,000 ha
Total	4,883,697,000 ha

Source: (FAO, 2010).

Organic @ 2.2 tons per hectare: 10.7 Gt of CO_2 (Azeez, 2009)

Annual GHG emissions: 49 Gt of carbon dioxide equivalent (CO_2e) (IPCC 2007c).

E. Potential exists for higher levels of CO_2 sequestration

All data sets that use averaging have outlying data. These are examples that are significantly higher or significantly lower than the average. They are always worth examining to find out why. Research into them will allow an understanding of which practices significantly increase soil carbon and which decrease or do not increase it.

There are several examples of significantly higher levels of carbon sequestration than the averages quoted in the studies above. The Rodale Institute in Pennsylvania, United States, has been conducting long-running comparisons of organic and conventional cropping systems for over 30 years, which confirm that organic methods are effective at removing CO_2 from the atmosphere and fixing it as organic matter in the soil. La Salle and Hepperly (2008:5) wrote: "*In the FST [farm systems trial] organic plots, carbon was sequestered into the soil at the rate of 875 lbs/ac/year in a crop rotation utilizing raw manure, and at a rate of about 500 lbs/ac/year in a rotation using legume cover crops.*

During the 1990s, results from the Compost Utilization Trial (CUT) at Rodale Institute – a 10-year study comparing the use of composts, manures and synthetic chemical fertilizer – show that the use of composted manure with crop rotations in organic systems can result in carbon sequestration of up to 2,000 lbs/ac/year. By contrast, fields under standard tillage relying on chemical fertilizers lost almost 300 pounds of carbon per acre per year".

Converting these figures into kilograms of CO_2 sequestered per hectare using the accepted conversion rate of 1 pound per acre = 1.12085116 kg/ha and soil organic carbon x 3.67= CO_2, gives the following results:

- The FST legume based organic plots showed that carbon was sequestered into the soil at the rate of about 500 lbs/ac/year. This is equivalent to a sequestration rate of 2,055.2 kg of CO_2/ha/yr.
- The FST manured organic plots showed that carbon was sequestered into the soil at the rate of 875 lbs/ac/year. This is equivalent to a sequestration rate of 3,596.6 kg of CO_2/ha/yr.
- The Compost Utilization Trial showed that carbon was sequestered into the soil at the rate of 2,000 lbs/ac/year. This is equivalent to a sequestration rate of 8,220.8 kg of CO_2/ha/yr.

Thus there are significant benefits from adding compost.

F. The potential in desert climates

Sekem is the oldest biodynamic farm in Egypt. It was founded in 1977 by Dr Ibrahim Abouleish. The Louis Bolk Institute and Soil&More, two organisations based in the Netherlands, have made a study to calculate soil carbon sequestration at Sekem. Their results show that, on average, Sekem's management practices have resulted in 900 kgs of carbon being stored in the soil per hectare per year in the fields that were 30 years old. Using the accepted formula of SOC x 3.67 = CO_2, this means that Sekem has sequestered 3,303 kg of CO_2 per hectare per year for 30 years (Luske and van der Kamp, 2009; Koopmans et al., 2011). Based on these figures, the widespread adoption of Sekem's practices globally has the potential to sequester 16 Gt of CO_2, which is around 30 per cent of the world's current GHG emissions, into soils (4,883,697,000 ha x 3,303 kgs = 16.1 gt CO_2/yr).

G. The potential in tropical climates

Researchers at the Royal Thai Organic Project near Chiang Mai in Thailand have managed to increase their soil organic matter levels from 1 per cent to 5 per cent over a period of eight years (personal communication). This means that 187.2 tons of CO_2/ha have been sequestered through this project, which equates to 23.4 tons of CO_2/ha/yr. If this was applied globally, it would sequester 114 Gt CO_2/ha/yr – more than double the world's current GHG emissions (4,883,697,000 ha x 23.4 tons of CO_2/ha/yr = 114 Gt CO_2/yr).

H. Deeper carbon systems

There is an emerging body of science which shows that the most stable fractions of soil carbon are stored deeper in the soil than most of the current soil carbon measurements used on farms. Most soil tests tend to work at a depth of around 15 to 20 cm, as this is the usual root zone for many crops. Research is finding that a significant amount of carbon is stored at lower depths and that this tends to be very stable.

Research by Rethemeyer and colleagues using radiocarbon techniques to analyse various soil carbon fractions indicated a progressive enrichment of stable organic compounds with increasing soil depth to 65 cm (Rethemeyer et al., 2005).

Research by Professor Rattan Lal and colleagues from Ohio State University compared carbon levels between no-till and conventional tillage fields and found that, in some cases, carbon storage was greater in conventional tillage fields. The key is soil depth. They compared the carbon storage between no-till and ploughed fields with the plough depth – the first 8 inches (20cm) of the soil – and found that the carbon storage was generally much greater in no-till fields than in plowed fields. When they examined 12 inches (30cm) and deeper, they found more carbon stored in ploughed fields than in the no-till ones. The researchers concluded that farmers should not measure soil carbon based just on surface depth. They recommended going to as much as 3 feet (1 metre) below the soil surface to get a more accurate assessment of soil carbon (Christopher, Lal and Mishra, 2009).

According to Gattinger and colleagues (2011:16), *researchers working on long-term comparison trials between organic and conventional farming systems in Switzerland (the DOK trials), found that, when rotation phases included two years of deep-rooting grass-clover leys, 64 percent of the total SOC stocks were deposited between 20–80 cm soil depths. "In many parts of the world, organic farming systems are relying on the soil fertility build-up of deep-rooting grass-legume mixtures and on the incorporation of plant residues by deep-digging earthworms, making it quite likely that the currently available data sets underestimate the SOC stocks in organically managed soils. This is particularly significant considering that in deeper soil horizons, SOC seems to be more stabilized." (Fliessbach et al., 1999)*

I. Grazing systems

The majority of the world's agricultural lands (68.7 per cent) are used for grazing (FAO, 2010). There is an emerging body of published evidence which shows that pastures and permanent ground cover swards in perennial horticulture build up soil organic carbon faster than any other farming system, and, with correct management, this is stored deeper in the soil (Fliessbach et al., 1999; Sanderman et al., 2010).

One of the significant reasons for this has been the higher proportion of plants that use the C4 pathway of photosynthesis as this makes them more efficient at collecting CO_2 from the atmosphere, especially in warmer and drier climates. According to Osborne and Beerling (2006:173), "*Plants with the C4 photosynthetic pathway dominate today's tropical savannahs and grasslands, and account for some 30% of global terrestrial carbon fixation. Their success stems from a physiological CO_2-concentrating pump, which leads to high photosynthetic efficiency in warm climates and low atmospheric CO_2 concentrations.*"

This knowledge is now being applied in innovative ways such as holistic stock management, evergreen farming, agroforestry in pastures and pasture cropping.

J. Pasture cropping

Pasture cropping works on the principle that annuals grow naturally through perennial pastures in their normal cycles. It is not the purpose of this paper to explain the technical details of how it is being successfully implemented in a wide variety of climates and soil types around the world. However, a brief overview has been included in Annex 1 to help understand the system. The critical issue for the purpose of this paper is to present the preliminary data on soil carbon sequestration so that the potential of this system can be further investigated.

Research by Jones at Winona, the property of Colin and Nick Seis in New South Wales, Australia, who use a combination of pasture cropping and holistic stock management, shows that 168.5 t/ha of CO_2 was sequestered over 10 years. The sequestration rate for the last two of the 10 years (2009 and 2010) was 33 tons of CO_2/ha/yr (Jones, 2012). This system can be, and is being, successfully used in both arable and pasture systems, including in horticulture. If this was applied around the world, it could potentially sequester 82 Gt of CO_2/yr (4,883,697,000 ha X 16.85 tonnes = 82 Gt).

This is significantly more than the world's GHG emissions of 49 Gt and would help reverse climate change. The increase in soil carbon would also significantly improve the production and adaptation capacities of global grazing systems.

K. The urgent need for more peer-reviewed research

It is not the intention of this paper to use the above types of generic exercises of globally extrapolating data as scientific proof of what can be achieved by scaling up organic systems. These types of very simple analyses are useful for providing a conceptual idea of the considerable potential of organic farming to reduce GHG emissions on a landscape scale. The critical issue here is that urgent peer-reviewed research is needed to understand how and why (and for the sceptics – if) these systems sequester significant levels of CO_2, and then look at how to apply the findings for scaling up on a global level in order to achieve a significant level of GHG mitigation.

The potential of these farming methods is enormous, considering that these data are based on current practices.

L. Permanence

One of the major debates around soil carbon is based on how it can meet the CDM 100-year permanence requirements.

Soil carbon is a complex mix of fractions of various carbon compounds. Two of these, humus and charcoal (char), are very stable: research shows that they can last for thousands of years in the soil. Other fractions are less stable (labile) and can be easily volatilized into CO_2. Soil carbon tends to volatilize into CO_2 in most conventional farming systems. However, correct management systems can continuously increase both the stable and labile fractions through a number of approaches, several of which are discussed later in this paper.

The research conducted by Jones at Winona showed that the majority of the newly increased soil carbon was in the stable fractions. She reported that 78 per cent of the newly sequestered carbon was in the non-labile (humic) fraction of the soil and this rendered it into highly stable long chain forms. Her research found that the carbon levels in the 0-10 cm increment were from the recent decomposition of organic matter and formed short-chain unstable carbon. The carbon below 30 cm was composed of the humic soil fraction and was highly stable (Jones, 2012). Jones's research is consistent with the findings of Christopher, Lal and Mishra, (2009) and Rethemeyer et al. (2005).

Long-term research conducted for more than 100 years at the Rothamsted Research Station in the United Kingdom and the University of Illinois Morrow Plots in the United States showed that the total soil carbon levels could steadily increase and then reach a new stable equilibrium in farming systems that use organic matter inputs. This means that good soil organic matter management systems can increase and maintain the labile fractions as well as the stable fractions over the time periods required by the CDM (Lal, 2007).

M. Adaptation

Even if the world stopped polluting the planet with GHGs, it would take many decades to reverse climate change. This means that farmers have to adapt to the increasing intensity and frequency of adverse and extreme weather events such as droughts and heavy, damaging rainfall. Indeed, many areas of the planet are already experiencing this (Anderson, 2010; Steer, 2011).

N. Greater resilience in adverse conditions

Published studies show that organic farming systems would be more resilient to the predicted weather extremes and could produce higher yields than conventional farming systems in such conditions (Drinkwater, Wagoner and Sarrantonio, 1998; Welsh, 1999; Pimentel et al., 2005; see also the comment of Nemes in this chapter). For instance, the Wisconsin Integrated Cropping Systems Trials found that organic yields were higher in drought years and the same as conventional in normal weather years (Posner, Baldock and Hedtcke, 2008).

Similarly, the Rodale FST showed that the organic systems produced more corn than the conventional system in drought years. The average corn yields during the drought years were 28–34 per cent higher in the two organic systems. The yields were 6,938 and 7,235 kg per ha in the organic animal and the organic legume systems, respectively, compared with 5,333 kg per ha in the conventional system (Pimentel et al., 2005). The researchers attributed the higher yields in the dry years to the ability of the soils on organic farms to better absorb rainfall. This is due to the higher levels of organic carbon in those soils, which makes them more friable and better able to store and capture rainwater, which can then be used for crops (La Salle and Hepperly, 2008).

O. Improved efficiency of water use

Research also shows that organic systems use water more efficiently due to better soil structure and higher levels of humus and other organic matter compounds (Lotter, Seidel and Liebhart, 2003; Pimentel et al., 2005).

Lotter and colleagues collected data for over 10 years during the Rodale FST. Their research showed that the organic manure system and organic legume system (LEG) treatments improve the soils' water-holding capacity, infiltration rate and water capture efficiency. The LEG maize soils averaged a 13 per cent higher water content than conventional system (CNV) soils at the same crop stage, and 7 per cent higher than CNV soils in soybean plots (Lotter, Seidel and Liebhart, 2003).

The more porous structure of organically treated soil allows rainwater to quickly penetrate the soil, resulting in less water loss from run-off and higher levels of water capture. This was particularly evident during the two days of torrential downpours from hurricane Floyd in September 1999, when the organic systems captured around double the amount of water as the conventional systems (Lotter, Seidel and Liebhart, 2003).

P. Critical differences between organic and conventional farming

Organic farming has a range of practices that are regarded as essential for allowing the system to be certified as organic. Most of these practices are easily transferrable to other farming systems, and many of them are now being adopted under the emerging term, "climate smart" agriculture (FAO, 2012c).

Q. The addition of organic matter

The term organic farming is derived from the fact that organic farming systems improve soil health and fertility through the recycling of organic matter. There is a very strong body of evidence which shows that the addition of organic matter improves soil organic carbon (SOC) levels and this is more effective than synthetic, water soluble fertilizers. Lal (2007:822) provides an extensive list from the scientific literature that demonstrates this:

"Application of manures and other organic amendments is another important strategy of SOC sequestration. Several long-term experiments in Europe have shown that the rate of SOC sequestration is greater with application of organic manures than with chemical fertilizers (Jenkinson, 1990; Witter et al., 1993; Christensen, 1996; Korschens & Muller, 1996; Smith et al., 1997). Increase in the SOC pool in the 0–30 cm depth by long-term use of manure compared to chemical fertilizers was 10% over 100 years in Denmark (Christensen, 1996), 22% over 90 years in Germany (Korschens & Muller, 1996), 100% over 144 years at Rothamsted, UK (Jenkinson, 1990) and 44% over 31 years in Sweden (Witter et al., 1993). The data from Morrow plots in Illinois indicated that manured plots contained 44.6Mgha−1 more SOC than unmanured control (Anderson et al., 1990). In Hungary, Arends & Casth (1994) observed an increase in SOC concentration by 1.0–1.7% by manuring. Smith et al. (1997) estimated that application of manure at the rate of 10Mgha−1 to cropland in Europe would increase the SOC pool by 5.5% over 100 years. In Norway, Uhlen (1991) and Uhlen & Tveitnes (1995) reported that manure application would increase SOC sequestration at the rate of 70–227Kgha−1yr−1 over 37–74-year period."

R. Composts' multiple benefits

Composting was pioneered by the organic farming movement through the work of Sir Albert Howard in the 1930s and 1940s, and then strongly promoted by Jerome Rodale in his numerous publications, especially in *Organic Farming and Gardening* that have been widely studied around the world (for more information, see www.rodaleinstitute.org).

There is an increasing body of evidence that composts are superior to raw manures in increasing the level of soil organic matter. The Rodale Institute studies have demonstrated that good organic practices using raw manures and cover crops can sequester 3,596.6 kg of CO_2/ha/yr and that when compost is added this increases to 8,220.8 kg of CO_2/ha/yr (LaSalle and Hepperly, 2008).

S. Avoided emissions

Currently, most of the food and other products from farms are exported from the farm and sent to cities. The disposal of the organic residues in land-fills is responsible for methane emissions. Methane is a significant GHG. Correct composting and bio-digester methods are now recognized as effective ways of avoiding such emissions (for more information on the science of soil methane and soil organic matter, see Annex 2). Research by FiBL shows that more GHGs can be avoided by these methods than by most other farming practices (Gattinger et al., 2011). For example the compost project at Sekem in Egypt has offset methane emissions since January 2007. By using the correct composting methods for organic materials, the project was able to reduce methane emissions by 303,757 tonnes of CO_2e (Helmy Abouleish, personal communication).

Composting the organic wastes in cities and transporting them to the farm brings multiple benefits in closing the nutrient cycle by returning the nutrients that are exported from the farm, avoiding methane emissions and increasing the rate of soil carbon sequestration.

T. Synthetic nitrogen fertilizers degrade soil carbon

One of the main reasons for the differences in soil carbon between organic and conventional systems is that, as research shows, there is a direct link between the application of synthetic nitrogenous fertilizers and a decline in soil carbon.

Scientists at the University of Illinois analysed the results of a 50-year agricultural trial and found that the application of synthetic nitrogen fertilizer had resulted in all the carbon residues from the crop disappearing, as well as an average loss of around 10,000 kg of soil carbon per hectare. This is around 36,700 kg of CO_2 per hectare over and above the many thousands of kilograms of crop residue that is converted into CO_2 every year (Khan et al., 2007; Mulvaney, Khan and Ellsworth, 2009). The researchers found that the higher the application of synthetic nitrogen fertilizer, the greater was the amount of soil carbon lost as CO_2. This is one of the major reasons why there is a decline in soil carbon in conventional agricultural systems and its increase in organic systems.

On the other hand there is a good body of research which shows that using legumes and carbon-based sources such as compost increases the levels of soil organic carbon (LaSalle and Hepperly, 2008).

Researchers from North America and Europe have also shown that organic systems are more efficient in using nitrogen than conventional farming systems. Significantly, because of this efficiency, very little nitrogen leaves the farms as GHGs or as nitrate that pollutes aquatic systems (Drinkwater, Wagoner and Sarrantonio, 1998; Mader et al., 2002).

U. Diverse cropping systems

Another critical aspect of organic production is the use of diverse cropping systems. Certified organic production systems prohibit continuous monocultures in cropping systems. Every certified organic farm needs to have a management plan that outlines its crop (and stock) rotation systems. Lal (2007:822) cites the scientific literature to indicate that this does make a difference:

"Soils under diverse cropping systems generally have a higher SOC pool than those under monoculture (Dick et al. 1986; Buyanoski et al. 1997; Drinkwater et al. 1998; Buyanoski & Wagner 1998). Elimination of summer fallow is another option for minimizing losses of the SOC pool (Delgado et al. 1998; Rasmussen et al. 1998). Growing a winter cover crop enhances soil quality through SOC sequestration. In the UK, Fullen & Auerswald (1998) reported that grass leys set aside increased SOC concentration by 0.02% per year for 12 years. In Australia, Grace & Oades (1994) observed that the SOC pool in the 0–10 cm layer increased linearly with increase in frequency of pasture in the crop rotation cycle. In comparison with continuous cropping, incorporation of cover crops in the rotation cycle enhanced SOC concentration in the surface layer by 15% in Sweden (Nilsson 1986), 23% in The Netherlands (Van Dijk 1982) and 28% in the UK (Johnston 1973) over [a] 12–28-year period. Similar results were reported by Lal et al. (1998) for the US cropland."

V. Erosion and soil loss

The highest percentage of soil carbon is contained in the first 10 cm of soil (Handrek, 1990; Handrek and Black, 2002; Stevenson, 1998). Soil loss and erosion from farming systems is a leading concern around the world (Millennium Ecosystem Assessment, 2005; IAASTD, 2009a). It is a major cause of loss of soil carbon since the highest levels of soil organic matter are in the top layer of the soil.

Comparison studies have shown that organic systems demonstrate less soil loss due to better soil health, and are therefore able to maintain greater soil productivity than conventional farming systems (Reganold, Elliott and Unger, 1987; Reganold et al., 2001; Mader et al., 2002; Pimentel et al., 2005). Reganold, Elliott and Unger compared the effects of organic and conventional farming on particular properties of the same soil over a long period and found, "*...the organically-farmed soil had significantly higher organic matter content, thicker topsoil depth, higher polysaccharide content, lower modulus of rupture and less soil erosion than the conventionally-farmed soil"* (Reganold et al., 1987: 370).

Critics of organic systems point to conventional, no-till production systems as superior to organic systems because the latter use tillage. To our knowledge, there is only one published study comparing conventional, no-till with organic tillage systems. The researchers found that the organic system had better soil quality. According to Teasdale, Coffman and Mangum (2007:1304*), "... the OR [organic] system improved soil productivity significantly as measured by corn yields in the uniformity trial ... higher levels of soil C and N were achieved despite the use of tillage (chisel plow and disk) for incorporating manure and of cultivation (low-residue sweep cultivator) for weed control... Our results suggest that systems that incorporate high amounts of organic inputs from manure and cover crops can improve soils more than conventional no-tillage systems despite reliance on a minimum level of tillage."*

The latest improvement in organic low/no-till systems developed by the Rodale Institute shows that these systems can deliver high yields as well as excellent environmental outcomes (Rodale, 2006; Moyer, 2011).

W. Soil carbon sequestration can help alleviate poverty

The agreements of the UNFCCC conference in Cancun proposed that hundreds of billions of dollars should be used for funding climate change mitigation activities. FAO believes that 70 per cent of the potential benefits from agricultural mitigation could go to farmers in developing countries (FAO, 2012c).

Schemes that pay farmers for sequestering carbon into the soil, could help alleviate rural poverty and provide a strong financial incentive to adopt good farming practices, if they are done fairly and properly. At an average of 2 tons of CO_2 per hectare at $20 per ton, farmers could earn $40 per hectare per year. While this may not seem like much, for many of the world's farmers working on only a few hectares and earning less than $400 a year, an extra $80 is extremely valuable. On a community scale, it would mean many thousands of dollars going into villages, which would be spent in the local community, creating the multiplier effect of added benefits. Very critically, if this is looked at over the long term, these amounts can become very worthwhile to the farmers. As an example, Sekem has sequestered 3,303 kgs of CO_2 per hectare per year for 30 years. At $20 a ton this is worth a total of $1,980 per hectare for the total time period (3.3 tons of CO_2 at $20 per ton = $66 /ha/yr).

Based on the results of the Royal Thai Organic Project, Thai farmers could earn $468 per hectare per year for eight years, which amounts to $3,744 per hectare for that time period (23.4 tons of CO_2 at $20 per ton = $468/ha/yr).

If farmers adopted systems similar to the Colin and Nick Seis pasture cropping methods used at Winona, they could earn $337 per hectare per year for 10 years, which totals $3,337 per hectare over that period (6.85 tons of CO_2 at $20 per ton = $337/ha/yr).

The most practical way to ensure smallholder farmers receive funding is for them to be organized into groups. The organic sector already does this with various group certification schemes, such as third-party systems and participatory guarantee systems (PGS). It would be relatively simple to include a soil carbon measurement system in current organic audit systems. Such systems could be grower controlled, and designed to ensure fairness and transparency so that the funds reach the farmers and their communities, rather than benefiting the money market traders.

Implemented properly, these schemes could be seen as social justice systems, where the CO_2-polluting industries would be paying many of the poorest people on the planet for their ecosystem services of sequestering GHGs. For example, 5 billion hectares at $40 per hectare has the potential to redistribute $200 billion from CO_2-polluting industries to rural communities. A significant proportion of this could go to smallholders in developing countries (FAO, 2012c).

Well-designed soil carbon schemes that include soil carbon sequestration have the potential to reduce GHG emissions in the atmosphere as well as alleviate rural poverty in developing countries, and they would provide a substantial financial incentive to adopt good farming practices.

They could be financed through government-administered cap and trade systems. These systems put a cap on the total amount of emissions, and, by taxing emissions that are above the targets, they force the emitters to reach their targets through energy efficiency, the adoption of renewable energy or by other offsets. The cap could be progressively lowered, thereby forcing the industries to continuously find ways to reduce emissions. These taxes could then be used to pay farmers for their ecosystem services of stripping the CO_2 out of the atmosphere and fixing it in the soil. The schemes could be government-administered or market-based.

There have been many concerns expressed about market-based systems, especially those that want to develop complex financial instruments as the trading basis for carbon. The collapse of the price for carbon in market-based systems as well as some schemes where most of the price has gone towards administering the scheme rather than paying the land holders show that there are major problems with these schemes. It is important that most of the funds go to the farmers, rather than to scheme administrators, brokers, carbon traders and other intermediaries. These experiences show the real need for adequate government regulation rather than allowing unregulated carbon markets.

The significant reduction in the price of carbon in 2011-2012 in the government administered European Union scheme shows the need for a realistic government mandated floor price for carbon to ensure that landholders are adequately compensated for their services of sequestering CO_2 and not subjected to the vagaries of market price fluctuations

One critical issue concerns ownership of the carbon. The carbon should belong to the farmer/landholder, and the payment should be for the service of sequestering it out of the atmosphere and storing it in the soil. The payment is not for the carbon, as this cannot and should not be separated from the soil.

Given the current trends of global GHG emissions and the worst case scenario we seem to follow for global warming it is critical that soil carbon is included in the UNFCCC processes and very importantly that there are mechanisms to financially reward farmers who engage in proven practices such as organic agriculture that sequester CO_2 into the soil.

Annex 1 to Commentary V:

Pasture cropping – annuals in a perennial system

Pasture cropping is where the annual crop is planted in a perennial pasture instead of in a ploghed field. This was first developed by Colin Seis in Australia. The principle is based on a sound ecological fact, namely that annual plants grow in perennial systems. The key is to adapt this principle to the appropriate management system for the specific cash crops and climate.

In Colin's system, the pasture is first grazed using holistic management to ensure that it is very short. This adds organic matter in the form of manure, cut grass and shed roots, and significantly reduces the competition from the pasture when the cash crop is seeded and germinates. The crop is directly planted in the pasture.

According the Colin Seis: "*It was also learnt that sowing a crop in this manner stimulated perennial grass seedlings to grow in numbers and diversity giving considerably more tones/hectare of plant growth. This produces more stock feed after the crop is harvested and totally eliminates the need to re-sow pastures into the cropped areas. Cropping methods used in the past require that all vegetation is killed prior to sowing the crop and while the crop is growing.*"

"From a farm economic point of view the potential for good profit is excellent because the cost of growing crops in this manner is a fraction of conventional cropping. The added benefit in a mixed farm situation is that up to six months extra grazing is achieved with

this method compared with the loss of grazing due to ground preparation and weed control required in traditional cropping methods. As a general rule, an underlining principle of the success of this method is 'One hundred percent ground cover one hundred percent of the time'."

"…a 20 Ha crop of Echidna oats that was sown and harvested in 2003 on …"Winona". This crop's yield was 4.3 tonne/Ha (31 bags/acre). This yield is at least equal to the district average where full ground disturbance cropping methods were used." This profit does not include the value of the extra grazing. On Winona, it is between $50 [and] $60/ha because the pasture is grazed up to the point of sowing. When using traditional cropping practices where ground preparation and weed control methods are utilised for periods of up to four to six months before the crop is sown then no quality grazing can be achieved.

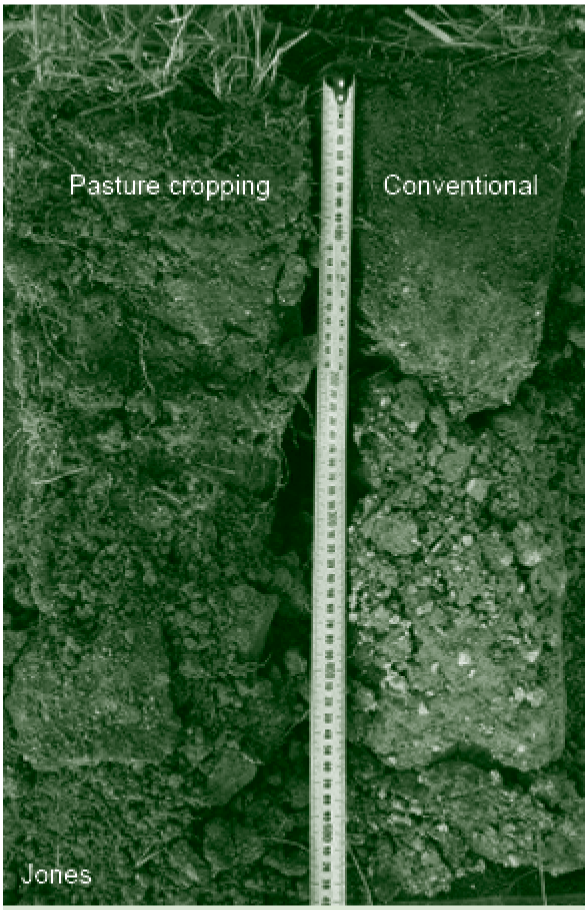
"Other benefits are more difficult to quantify. These are the vast improvement in perennial plant numbers and diversity of the pasture following the crop. This means that there is no need to re-sow pastures, which can cost in excess of $150 per hectare and considerably more should contractors be used for pasture establishment."

Independent studies at Winona on pasture cropping by [the] Department of Land and Water have found that pasture cropping is 27% more profitable than conventional agriculture [and] this is coupled with great environment benefits that will improve the soil and regenerate our landscapes."

Building soil fertility without synthetic fertilizers

Christine Jones has conducted research at Colin Sies's property which shows that in the last 10 years 168.5 t/ha of CO_2 was sequestered:

- The sequestration rate in the last two years (2008–2010) has been 33 tons of CO_2 per hectare per year.



Comparison of soil between Winona and neighbour

In this paired site comparison, parent material, slope, aspect, rainfall and farming enterprises are the same. Levels of soil carbon in both paddocks were originally the same.
LHS: 0–50 cm soil profile from a paddock in which groundcover has been actively managed (cropped and grazed) to enhance photosynthetic capacity.
RHS: 0–50 cm soil profile from a conventionally managed neighbouring paddock (10 metres through the fence) that has been set-stocked and has a long history of phosphate application.

Notes:
i) The carbon levels in the 0–10 cm increment are very similar. This surface carbon results from the decomposition of organic matter (leaves, roots, manure etc), forming short-chain unstable 'labile' carbon.
ii) The carbon below 30 cm in the LHS profile has rapidly incorporated into the humic (non-labile) soil fraction. Long-chain, non-labile carbon is highly stable.

(Jones, 2012)

- This increase occurred during the worst drought in recorded Australian history.
- The following increases in soil mineral fertility have occurred in 10 years with only the addition of a small amount of phosphorus: calcium 277 per cent, magnesium 138 per cent, potassium 146 per cent, sulphur 157 per cent, phosphorus 151 per cent , zinc 186 per cent, iron 122 per cent, copper 202 per cent, boron 156 per cent, molybdenum 151 per cent, cobalt 179 per cent and selenium 117 per cent (Jones, 2012).

For more information on:

- Pasture cropping, see: http://www.winona.net.au/farming.html.
- Holistic management, see: http://holisticmanagement.org.

Annex 2 to Commentary V: Methane: Soil management can reduce atmospheric methane

The science on soil methane and soil organic matter is still in its infancy, with many unanswered questions due to the lack of research. However, a recent meta study by van Groenigen, Osenberg and Hungate (2011) has shown that methane output from the soil will increase as the climate warms, which raises concerns that the percentages of GHGs that are sequestered in forestry systems are overestimated.

The methane model used by van Groenigen et al. measured what was volatilized, but not the amount of the methane that was biodegraded in the soil. Methane is produced and degraded as a natural cycle in nature, and most of this degradation takes place in biologically active soils and in the oceans by methanotrophic microbes.

Historically, apart from a few exceptional events during geological time periods, the amount of methane in the atmosphere from the enormous herds of grazing animals on the prairies, savannahs and steppes, and from the decay of organic matter in the vast forests and wetlands of the planet was relatively stable until human activities over the last 200 years disrupted the natural cycles of methane production and degradation (Heimann, 2011; Murat et al., 2011).

Studies by Hellebrand and Herppich (2000) and Levine et al. (2011) showed that a significant amount of methane is biodegraded in soils, and that this has been underestimated due to a lack of research. While the van Groenigen et al. study shows an increase in methane output from soils when the temperature increases, the Hellebrand and Herppich studies show that the increase in temperature will drive up the rate of biological degradation of methane by methylotropic bacteria and other methanotrophic microorganisms. This explains why historical atmospheric methane levels have been relatively stable, and also why naturally produced methane levels may not increase as the climate gets warmer.

Many studies of methane production only calculate the methane produced by the systems as a one-way output into the atmosphere. This can be correct for some production systems, such as confined animal feed lots and garbage sent to land fill; however, it is not correct for most natural productions systems, such as animal grazing on grasslands, crop production on biologically active soils, orchards and forests, as these systems are based on cycles that also degrade methane. This oversight of the amount of methane that can be biodegraded by the soil or the oceans is a major flaw that needs to be rectified.

Until the decay cycles are properly identified, measured and modelled, the amounts of methane that are emitted by systems are not an accurate measure of methane's contribution to total GHGs. Understanding these cycles and the biological conditions needed to biodegrade methane will give scientists and landholders a major tool to manage one of the most important GHGs.

The need for good soil management practices

A study by Fuu Ming Kai et al. (2011) suggests that the recent reductions in methane output are due to changes in farming practices. This study adds to the data showing that there is good evidence of the potential to reduce the amount of methane in the atmosphere through the following soil management practices as described below:

1. *Avoiding anaerobic soil conditions*. Methane forms in anaerobic conditions such as rice paddies. New methods, such as the system of rice intensification (SRI), use more frequent, shorter watering cycles that avoid anaerobic conditions, thereby significantly reducing methane production.
2. *Open well-aerated soils*. Organic matter can volatilize into CO_2, methane and other gases in farming systems. However, correct management systems can continuously increase the proportion of the non-volatile compounds and form stable fractions of soil organic matter. The research conducted by Jones at Winona showed that the majority of the newly increased soil carbon was in the stable fractions; 78% of the newly sequestered carbon was in the non-labile (humic) fraction of the soil, rendering it highly stable.
3. *Promoting biologically active soils with high levels of methanothropic microbes*. The research by Levine et al. (2011) found that the key to methane degradation is land management practices that achieve high levels of diversity of methanothropic microbes.

Research needs to be conducted into all of these areas to accurately establish the best practices. This must be based on criteria that are measurable, replicable and easily adopted by land managers.

Commentary VI: Agroecology: A Solution to the Crises of Food Systems and Climate Change

Olivier de Schutter
UN Special Rapporteur on the Right to Food

Abstract

The food price hikes of 2008 and 2011–2012 were partly the result of weather-related events linked to climate change, and partly due to the dependence of food production on fossil energies that caused a merger between food and energy markets (on this issue, see also the comment by Rundgren in this chapter) as well as the financialization of food markets. The current efforts to reinvest in agriculture should take into account the need to improve the resilience of food systems so as to reduce their vulnerability to extreme weather events and to the increasingly volatile prices of non-renewable fossil energies. This article explores how agroecology, understood as the application of the science of ecology to agricultural systems, can result in modes of production that are not only more resilient, but also both highly productive and sustainable, enabling them to contribute to the alleviation of rural poverty, and thus, to the realization of the right to food.

A. Reinvesting in agriculture

The food price spikes of 2008 and 2011–2012 prompted governments to start reinvesting in agriculture, a sector that has been neglected in many developing countries for the past 30 years. However, investments that increase food production will not make significant progress in combating hunger and malnutrition if they do not lead to higher incomes and improved livelihoods for the poorest – particularly small-scale farmers in developing countries. And short-term gains will be offset by long-term losses if they cause further degradation of ecosystems, thus threatening the ability to maintain current levels of production in the future. The question, therefore, is not simply *how much*, but also *how* the investments are made. Pouring money into agriculture will not be sufficient; the imperative today is to take steps that facilitate the transition towards a low-carbon, resource-conserving type of agriculture that benefits the poorest farmers.

Agroecology can play a central role in achieving this goal (De Schutter, 2010a; De Schutter and Vanloqueren, 2011). It is possible to significantly improve agricultural productivity where it has been lagging behind, and thus to increase production where it needs most to be increased (i.e. primarily in poor, food-deficient countries), while at the same time improving the livelihoods of smallholder farmers and conserving ecosystems. This would also slow the trend towards increasing urbanization in the countries concerned, which is placing stress on their public services. Moreover, it would contribute to rural development and preserve the ability of succeeding generations to meet their own needs. In addition, the resulting higher incomes in the rural areas would contribute to the growth of other sectors of the economy by stimulating demand for non-agricultural products (Adelman, 1984).

B. The diagnosis

Since the global food crises, most of the focus has been on increasing overall production using methods consistent with classic Green Revolution approaches. The crises have been attributed to a mismatch between supply and demand, reflecting a gap between slower productivity growth and increasing needs. A widely cited estimate is that, taking into account demographic growth as well as changes in the composition of diets and consumption levels associated with growing urbanization and higher household incomes, the overall increase in agricultural production should reach 70 per cent by 2050 (Burney et al., 2010).

However, apart from the fact that this estimate takes the current demand curves as given and does not consider the leakages and waste in the current food systems (UNEP, 2009), the focus on increasing production may not adequately consider the fact that hunger today is not so much a consequence of stocks being too low or to global supplies being unable to meet demand; rather it is due to poverty. It is their lack of purchasing power that makes it difficult for the poorest segments of the population, including marginal small-scale farmers who are often net-food buyers, to withstand economic shocks such as those that result from sudden increases in the prices of basic food commodities. Increasing the incomes of the poorest is therefore the best way to combat hunger. Investment in agriculture is needed, but it should not only foster production to meet growing needs; it should also reduce rural poverty by boosting the incomes of small-scale farmers. Only by supporting small producers will it be possible to help break the vicious cycle that leads from rural poverty to the expansion of urban slums, in which poverty breeds more poverty.

In addition, agriculture must not compromise on its ability to satisfy future needs. The loss of biodiversity (Esquinas-Alcázar, 2005; Swanson, 2005), the unsustainable use of water, as well as the degradation and pollution of soils and water, undermine the continuing ability of the earth's natural resources to support agriculture. Climate change, which translates into more frequent and extreme weather events, such as droughts and floods, and less predictable rainfall, is already severely affecting the ability of certain regions and communities to feed themselves, and it is destabilizing markets. The change in average temperatures is threatening the ability of entire regions, particularly those where rain-fed agriculture is practiced, to maintain their existing levels of agricultural production (Stern, 2007; IPCC, 2007b). Less fresh water will be available for agricultural production, and the rise in sea levels is already causing the salinization of water in certain coastal areas, rendering that water unsuitable for irrigation purposes.

As is well known, current agricultural practices are exacerbating this situation in a number of ways. For instance, deforestation to enable the expansion of cultivated areas, represents a major source of carbon dioxide (CO_2) emissions (accounting for 17 per cent of total anthropogenic GHG emissions), while methane (CH_4) emissions result from rice paddies and livestock digestion (accounting for 14.3 per cent of emissions). Another GHG emission is nitrous oxide (N_2O), which is produced in particular through the Haber-Bosch process of fabricating nitrogen-based fertilizers (accounting for another 7.2 per cent) (Allen et al., 2009; Meinhausen et al., 2009).

Agroecology is increasingly seen as one way to address these considerable challenges. A wide range of experts within the scientific community and international agencies such as the FAO and Bioversity International (2007), and UNEP (2005) view it as a way to improve the resilience and sustainability of food systems (IAASTD, 2009a; Wezel et al., 2009a). It is also gaining ground in countries as diverse as Brazil, France, Germany and the United States (Wezel et al., 2009).

C. Agroecology: mimicking nature

Agroecology has been defined as the "application of ecological science to the study, design and management of sustainable agroecosystems" (Altieri, 1995; Gliessman, 2007). It seeks to improve agricultural systems by mimicking or augmenting natural processes, thus enhancing beneficial biological interactions and synergies among the components of agrobiodiversity (Altieri, 2002). Common principles of agroecology include recycling nutrients and energy on farms, rather than augmenting nutrients with external inputs; integrating crops and livestock; diversifying species and genetic resources in the agroecosystems over time and space, from the field to landscape levels; and improving interactions and productivity throughout the agricultural system, rather than focusing on individual species. Agroecology is highly knowledge-intensive, based on techniques that are not delivered top-down but developed on the basis of farmers' knowledge and experimentation.[33] Its practices require diversifying the tasks on the farm and linking them to the diversity of species (including animals) that interact at field level.

A variety of techniques have been developed and successfully tested in a range of regions that are based on this approach (Pretty, 2008). *Integrated nutrient management* reconciles the need to fix nitrogen in the soil by importing inorganic and organic sources of nutrients and reducing nutrient losses through erosion control. Thus it also builds up soil organic matter, which enhances soil fertility and can bind significant amounts of carbon in the soil (see commentary of Leu on this issue in this chapter). *Agroforestry* incorporates multifunctional trees into agricultural systems. *Water harvesting* in dryland areas enables the cultivation of formerly abandoned and degraded lands, and improves the water productivity of crops. The *integration of livestock into farming systems*, such as dairy cattle, pigs and poultry, including using zero-grazing cut and carry practices, provides a source of protein to families while also fertilizing soils. The incorporation of fish, shrimps and other aquatic resources into farm systems, such as into irrigated rice fields and fish ponds, provides similar benefits. These approaches involve the maintenance or introduction of agricultural biodiversity as a result of the integration of diverse crops, livestock, agroforestry, fish, pollinators, insects, soil biota and other components.

Such resource-conserving, low-external-input techniques have a huge, yet still largely untapped, potential to address the combined challenges of production, combating rural poverty and contributing to rural development, while also preserving ecosystems and mitigating climate change.

1. Agroecology as a response to supply constraints

Agroecological techniques have a proven potential to significantly improve yields. Pretty et al. (2006) compared the impacts of 286 recent sustainable agriculture projects in 57 developing countries covering 37 million ha (representing 3 per cent of their cultivated area). They found that the interventions increased crop productivity on 12.6 million farms by an average of 79 per cent, while also improving the supply of critical environmental services.[34] A large-scale study by Foresight (2011a) on Global Food and Farming Futures, commissioned by the Government of the United Kingdom, which reviewed 40 projects in 20 African countries where sustainable intensification was developed during the 2000s, reached similar conclusions.[35]

2. The potential of agroecology to increase the incomes of small-scale farmers

One advantage of agroecology is its reliance on locally produced inputs. Many African soils are nutrient-poor and heavily degraded, and therefore need replenishment. Adding nutrients to the soil can be done by applying not only mineral fertilizers, but also livestock manure or by growing green manures. Farmers can also establish what has been called a "fertilizer factory in the fields" by planting trees that take nitrogen out of the air and "fix" it in their leaves, which are subsequently incorporated into the soil (World Agroforestry Centre, 2009). Agroecology reduces the dependence of farmers on access to external inputs – and thus on subsidies – and on local retailers of fertilizers or pesticides as well as on local moneylenders. Diversified farming systems produce their own fertilizers and pest control systems, thus reducing the need for pesticides (De Schutter, 2004). The local availability of adapted seeds, planting materials and livestock breeds also offers multiple advantages, both for the farmer and for ensuring the supply of the required diversity of such materials for major crops such as maize, rice, millet, sorghum, potato and cassava (De Schutter, 2009a). This is particularly beneficial to small-scale farmers – especially women – who have low or no access to credit, and also lack capital and access to fertilizer distribution systems, particularly since the private sector is unlikely to invest in the most remote areas where communication routes are poor and where few economies of scale can be achieved.

3. Agroecology's contribution to rural development and to other sectors of the economy

Agroecology contributes to rural development because it is relatively labour-intensive and is most effectively practiced on relatively small plots of land. The initial period is particularly labour-intensive because of the complexity of the tasks of managing different plants and animals on the farm and of recycling the waste produced, but this higher labour intensity of agroecology diminishes significantly in the longer term (Ajayi et al., 2009).[36] And although it is seen by many as a liability of sustainable farming, especially where governments give priority to labour-saving measures, the creation of employment in the rural areas in developing countries may in fact constitute an advantage if linked to productivity gains. Indeed, it could present an enormous advantage in the context of massive underemployment and high demographic growth in many developing countries. It would also respond to the urgent need to slow down rural-urban migration, as activities in the services sector in the urban areas appear unable to absorb the excess labour. Growth in agriculture can be especially beneficial to other sectors of the economy if it is broad-based and increases the incomes of a large number of farming households, rather than leading to a further concentration of incomes in the hands of a few relatively large landowners who rely on large-scale, heavily mechanized plantations (Adelman, 1984).

4. Agroecology's contribution to improving nutrition

The approaches espoused by the Green Revolution in the past focused primarily on boosting the production of cereal crops – rice, wheat and maize – in order to prevent famines. However, these crops are mainly a source of carbohydrates and contain relatively few proteins and the other nutrients essential for adequate diets. Yet, of the over 80,000 plant species available to humans, these three crops supply the bulk of our protein and energy needs today (Frison et al., 2006). The shift from diversified cropping systems to simplified cereal-based systems has thus contributed to micronutrient malnutrition in many developing countries (Demment et al., 2003). As a result, nutritionists now increasingly insist on the need for more varied agroecosystems, in order to ensure a more diversified nutrient output from farming systems (Alloway, 2008; DeClerck et al., 2011). The diversity of species on farms managed following agroecological principles, as well as in urban or peri-urban agriculture, is an important asset in this regard.

5. Agroecology and climate change

Agroecology can support the provision of a number of services to ecosystems, including by providing a habitat for wild plants, supporting genetic diversity and pollination, and water supply and regulation. It also strengthens resilience to climate change which is causing more extreme weather-related events. Resilience is strengthened by the use and promotion of agricultural biodiversity at ecosystem, farm system and field levels, made possible by many agroecological approaches (Platform for Agrobiodiversity Research, 2010). Agroecology also puts agriculture on the path of sustainability by delinking food production from a reliance on fossil energy (oil and gas). In addition, it contributes to mitigating climate change, both by increasing carbon sinks in soil organic matter and above-ground biomass, and by reducing CO_2 and other GHG emissions through lower direct and indirect energy use.

D. Scaling up agroecology

There is a clear and urgent need for a reorientation of agricultural development towards systems that use fewer external inputs linked to fossil energies, and instead use plants, trees and animals in combination, mimicking nature instead of industrial processes at the field level. However, the success of such a reorientation will depend on the ability to learn faster from recent innovations and to disseminate what works more widely. Governments have a key role to play in this regard. Encouraging a shift towards sustainable agriculture implies transition costs, since farmers must learn new techniques and revitalize traditional and local knowledge, moving away from the current systems that are both more specialized and less adaptive, and have a lower innovation capacity (Pretty, 2008). In order to succeed in implementing such a transition, the spread of agroecology should be directed at the farmers themselves, who will be its main beneficiaries. Thus farmer-to-farmer learning in farmer field schools or through farmers' movements should be encouraged, as in the Campesino-a-Campesino movement in Central America and Cuba (Degrande et al., 2006; Holt-Giménez, 2006; Rosset et al., 2011).

An improved dissemination of knowledge by horizontal farmer-to-farmer means transforms the nature of knowledge itself, which becomes the product of a network (Warner and Kirschenmann, 2007). It should encourage farmers, particularly small-scale farmers living in the most remote areas and those eking out a living from the most marginal soils, to work with experts towards a co-construction of knowledge, ensuring that advances and innovative solutions will benefit them as a matter of priority, rather than only benefiting the better-off producers (Uphoff, 2002a).

This is key to the realization of the right to food. First, it enables public authorities to benefit from the experiences and insights of the farmers. Rather than treating smallholder farmers as beneficiaries of aid, they should be seen as experts who have knowledge that is complementary to formalized expertise. Second, participation can ensure that policies and programmes are truly responsive to the needs of vulnerable groups, as those groups will question projects that fail to improve their situation. Third, participation empowers the poor – a vital step towards poverty alleviation, because lack of power is a source of poverty, as marginal communities often receive less support than the groups that have better connections with government. Moreover, poverty exacerbates this lack of power, creating a vicious circle of further disempowerment. Fourth, policies that are co-designed with farmers have greater legitimacy, and thus favour better planning of investment and production and better uptake by other farmers (FAO and IIED, 2008). Participation of food-insecure groups in the policies that affect them should become a crucial element of all food security policies, from policy design to the assessment of results to the decision on research priorities. Indeed, improving the situation of millions of food-insecure smallholder farmers cannot be done without them.

Commentary VII: Promoting Resilient Agriculture in Sub-Saharan Africa as a Major Priority in Climate-Change Adaptation

Marcus Kaplan, Chinwe Ifejika-Speranza, and Imme Scholz
German Development Institute/ Deutsches Institut für Entwicklungspolitik (DIE)

Abstract

- Policies to promote adaptation to climate change in sub-Saharan Africa, while also helping to alleviate poverty, will require multiple investments in rural areas to raise agricultural productivity and improve economic infrastructure and social services as priorities.
- Increased investment in agriculture should take into account its multiple social, economic and environmental functions in order to achieve poverty reduction and food security, and improve the resilience of rural livelihoods to multiple shocks, including climate change.
- Scenarios of the local impacts of climate change should include extreme weather and climate conditions (i.e. with regard to temperature or variability of rainfall) in order to be prepared for the effects of dangerous climate change (i.e. more frequent and intensive droughts and floods) that, in the worst case, could force local populations to permanently move out of affected areas.

A. Challenges facing agriculture in sub-Saharan Africa

Agricultural production in sub-Saharan Africa (SSA), and therefore also livelihoods that depend on agriculture, will be severely affected by the impacts of climate change. Depending on their geographical location, various subregions are likely to experience either less or more rainfall, rising temperatures, and a higher number and intensity of extreme weather events. Generally, yields will decline, although tolerance of different crops to temperature changes and water availability will vary considerably (Lobell et al., 2008; Liu et al., 2008). While the major trends are clear, considerable uncertainties remain (Müller, 2009). For example, for a number of areas in Western Africa some global circulation models expect increases in precipitation, while others project less rainfall for the coming decades. Despite this uncertainty, agriculture throughout Africa faces a serious risk of experiencing negative impacts from climate change (Müller et al., 2011b). Under such circumstances, it will be particularly challenging for poor farmers to prepare for the upcoming changes. It is therefore advisable to focus not only on direct measures to support adaptation of agricultural activities to the impacts of climate change, but also to take a broader view and aim to increase the overall resilience of rural people and their livelihoods.

Most poor people in developing countries live in rural areas (The World Bank, 2008), many of whom depend on agricultural activities for two purposes: first to ensure food security for their families, and second, for income generation, as agriculture is often their main or even only economic activity. Both aspects also have implications for other, non-farm rural households, either through the degree of availability of food, which can cause fluctuations in local prices, or as an indirect source of employment.

In many rural areas of SSA, agriculture faces various well-known challenges, which constrain the social and economic development of the sector and of the people who depend on it. The fundamental constraints include insecure access of local producers to land, unskilled agricultural manpower for innovative agricultural production systems, limited access to agricultural inputs, as well as limited knowledge of how the local climate (e.g. homogeneous rainfall zones that extend over villages) is changing and is expected to change in the future. These constraints result in lower productivity (Bruinsma, 2009; Rosegrant et al., 2001) and the prevalence of unsustainable agricultural practices, with negative ecological impacts. Water stress and scarcity are increasing, while biodiversity is declining. Soil degradation and declining fertility through, for example, inappropriate soil management and low inputs, create serious problems for current and future agricultural productivity in many parts of SSA (McIntyre et al. 2009a; Vlek, Le and Tamene, 2008). Furthermore, low-output agriculture necessitates the use of more land to maintain its level of production, which is why agriculture is the main driver of deforestation in nearly all developing countries (Scherr and Sthapit, 2009). Such land-use changes for food production cause CO_2 emissions through the release of carbon from above-ground biomass and grazing livestock, reduced carbon sequestration in soils and unsustainable agricultural practices (Scherr and Sthapit, 2009). As a result, land-use changes (including deforestation) account for about 17 per cent of total anthropogenic GHG emissions (Smith et al., 2007b), while biomass burning and the conversion of wetlands contribute to methane (CH_4) emissions, and the application of fertilizers results in nitrous oxide emissions (UNFCCC, 2008).

Today, new global patterns create additional challenges that further aggravate these known constraints on a productive and sustainable agricultural sector in SSA. In addition to economic trends, such as greater international competition for land for various uses, fluctuating food prices, higher energy prices, and international trade policies, climate change seriously threatens the productivity of the agricultural sector and its contribution to economic and social development. The poorer people who depend directly on ecosystem services for their livelihoods are the most vulnerable to permanent changes in temperature and water availability, as well as to an overall higher variability in climatic patterns. They not only have less access to various types of resources, but they also have fewer opportunities for diversifying their livelihoods to include other income-generating activities in order to reduce their dependence on agriculture and other ecosystem services.

One of the main reasons for the poor situation and the high vulnerability of farmers and agriculture in SSA is the long-term neglect of this sector by both national governments and the international donor community starting in the 1980s. Public spending on farming accounts for only 4 per cent of total government spending in SSA (World Bank, 2008), and the agricultural sector is taxed at a relatively high level. In addition, the share of the agricultural sector in official development assistance (ODA) declined from 18 per cent in 1979 to 3.5 per cent in 2004 (World Bank, 2008). Today, the importance of agriculture for economic growth has generally been recognized, and national, regional and international organizations are making greater efforts to support its development (Challinor et al., 2007; Hazell et al., 2007). In their Maputo Declaration of 2003, member countries of the African Union called upon African governments to increase investment in the agricultural sector to at least 10 per cent of their national budgets. However, most African countries are still far from reaching this target. Moreover, even though the sector is now receiving more attention, owing to the long period of neglect, the many challenges ahead will be difficult to overcome.

Furthermore, most public transfers are largely aimed at mitigating climate change rather than supporting adaptation to its impacts: 79 per cent of dedicated multi- and bilateral funds were approved for mitigation projects (84 per cent if activities for reducing emissions from deforestation and forest degradation (REDD) are included), and only 14 per cent for adaptation projects.[37] Bilateral ODA shows a slightly different pattern, with 70 per cent approved for mitigation and 30 per cent for adaptation (UNEP, 2010). Moreover, most activities and funds focus on reducing emissions and increasing efficiency in the energy and transport sectors, while adaptation and mitigation in agriculture are still underfunded. Looking at bilateral ODA again, agriculture received only 1 per cent of all funds dedicated to mitigation, compared with 10 per cent for adaptation activities in 2009 (UNEP, 2010).

B. Options for multifunctional agriculture and resilient livelihoods

The various constraints on African agriculture as outlined above call for multifunctional approaches that increase the resilience of agricultural systems and livelihoods to the impacts of external disturbances, including climate change. Such agricultural management should aim to contribute to food security and to support economic and social development for all stakeholders, while at the same time minimizing negative impacts on ecosystems. Taking into account the large contribution of the agricultural sector to global greenhouse gas (GHG) emissions, a comprehensive approach should also strive to avoid management practices that increase emissions. Indeed, there are various approaches that may even contribute to reducing agricultural GHG emissions if implemented properly.

Due to the currently low productivity of agriculture in SSA, there is a large potential for improvements towards resilient and multifunctional practices. Most of these sustainable management practices were already well known before the impacts of climate change increased the urgency of their implementation. In their most comprehensive form, integrated approaches also take into account impacts of agricultural and land-use management on local livelihoods, social equity and inclusion, and are part of wider integrated natural resources management (IAASTD, 2009b). Integrated systems do not require a single, strictly defined technology; rather they require a set of varying practices adapted to local biophysical and socio-economic conditions. All these approaches have one feature in common: they seek to depend less on external inputs. Instead, they rather manage the complex dynamics and interactions between different components of agroecosystems and adjoining ecosystems by mimicking nature and by relying on technologies and inputs that are available within the system (De Schutter, 2011; Buck and Scherr, 2011). Integrated systems support adaptation to climate change by strengthening the resilience of the agroecosystem to any disturbances, by increasing the degree of diversification and improving the provision of environmental services. At the same time, their low use of fertilizers and other external inputs can reduce adverse impacts on ecosystem components and result in lower emissions from the production and transport process. Instead of relying on large quantities of external material inputs, farmers' knowledge is the major resource, and key to the appropriate application of inputs and to the successful implementation of new management practices.

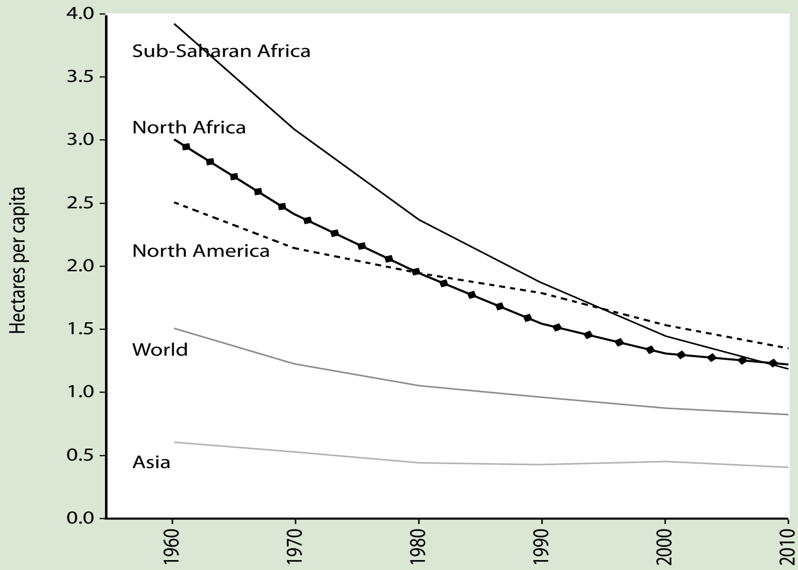
It is still uncertain whether multifunctional and integrated management practices can ensure food security and whether they are competitive with conventional, high-input agricultural systems with regard to productivity. While these aspects are still the subject of ongoing discussions (Badgley et al., 2007; Connor, 2008, Gianessi, 2009; Pimentel et al., 2005), there is some evidence that, compared with high-yielding systems in developed countries, organic agriculture and other types of integrated approaches result in lower yields (Badgley et al., 2007; Connor, 2008). However, in many regions in SSA, low-input systems prevail, some of which can be regarded as organic systems, as they use few, if any, external inputs that are either not accessible or are too expensive. In such systems, a complete shift to integrated and adequately managed systems may increase yields (Badgley et al., 2007; Pretty, 2008; UNEP-UNCTAD, 2008). (For a more detailed discussion of the productivity and profitability of organic agriculture, see the commentary of Nemes in this chapter.)

The African continent still faces the highest population growth rates in the world (FAO, 2006; Binswanger-Mkhize, 2009). This, along with current deficiencies in food security and possible future changes in diets, reinforces the urgency to increase agricultural production. Whether this objective should be mainly pursued by either intensifying production on existing agricultural land or by expanding agricultural land to previously unused areas, is currently an issue of debate. Even in a land-rich continent such as Africa, the amount of land suitable for agricultural purposes is declining rapidly (figure 10), and the conversion of other land uses (particularly forests) for agricultural purposes produces additional CO_2 emissions (figure 11). Moreover, land conversion may jeopardize the livelihoods of people who generate ecosystem services from the former land uses (for a more elaborate discussion, see the comments of Pimentel and GRAIN in this chapter).

Intensification, on the other hand, may either be implemented through integrated agroecological approaches, as outlined above, or through larger scale conventional agriculture, which may increase pressure on natural resources and which also runs the risk of leaving smallholders behind. The process of intensifying production on existing agricultural land needs improvements in agricultural management and/or additional inputs, particularly either mineral or organic fertilizers. However, intensifying production requires access to these inputs (which currently remain unaffordable to local farmers) and to knowledge and information in order to implement new management practices in an appropriate way. Otherwise, additional inputs may result in higher emissions of nitrous oxide and carbon dioxide.

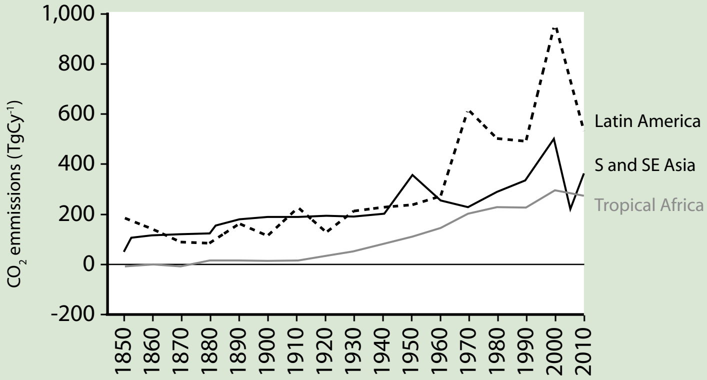
However, even if governments and the international community were to pay greater attention to the agricultural sector, it is likely that in some areas agriculture will become extremely difficult or will no longer be viable due to climate change and

Figure 10: Land for agricultural use, 1960–2010 (ha per capita)



Source: Based on FAOSTAT.

Figure 11: CO_2 emissions from land-use change in selected developing regions, 1850–2009



Source: Global Carbon Project, 2010.

environmental degradation (e.g., Fischer et al., 2005). In those instances, adaptation strategies should be adopted that aim to diversify the livelihoods of rural households. Diversification in farming relates to risk spreading through various agricultural practices (such as agroforestry) or mixed crop-livestock systems (that rely on a larger number of different crops and/or livestock products) to reduce the threat of crop failure in case of unfavourable climatic conditions. Income diversification into non-farm activities reduces the direct dependence on ecosystem services, and can often generate higher incomes than agricultural activities. This supplementary income can again be used for additional investments in agricultural activities, which in turn could increase income generation from farming (Ellis and Freeman, 2004). Other aspects, such as improvement of education in rural areas (Jayne, Mather and Mghenyi, 2010) or better infrastructure, may also contribute to increasing the resilience of rural livelihoods without being directly related to agriculture.

C. Increasing the resilience of agricultural systems

Domestic and external interventions to develop and strengthen agriculture will have to overcome the fundamental constraints on agricultural development in SSA, such as lack of access to land, agricultural inputs as well as knowledge and information, noted above. If these constraints are not addressed, adaptation to climate change will only be dealing with the symptoms of low adaptive capacity, high vulnerability and low resilience. The constraints are jeopardizing agricultural production at a time when the impacts of climate change can already be observed. Thus there is no time left to allow a sequence of first addressing the fundamental issues before responding to climate change. Rather, all current challenges have to be tackled through an integrated effort, together with appropriate measures to support adaptation and increase the overall resilience of agricultural systems and rural livelihoods.

Specific options for domestic action and external support for those actions are discussed below.

1. Providing access to land

Proper land reform, land registration and secure land-tenure rights for women and men need to be guaranteed to enable investment in sustainable farming practices, the benefits of which often accrue only in the long term. Recently, increased foreign direct investment in land has received much attention in Africa as it contributes – at least in some countries – to compromising traditional land use rights (for a more elaborate analysis, see the comment of Mittal in chapter 4). For these reasons, international guidelines for managing the impacts on local land tenure of large (foreign) investments in land are needed. The recent successful conclusion of intergovernmental negotiations on *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests* (FAO, 2011) led by the Committee on World Food Security (CFS) and the report of the High Level Panel of Experts of the CFS (FAO, 2011c) marks a starting point. It is vital that national governments follow these guidelines, review their land laws and incorporate checks and balances to ensure that the investments improve rural development, are pro-poor and do not jeopardize adaptive capacities.

Investment impact assessments are another helpful instrument. They should be carried out prior to a land investment, and need to analyse: (i) whether and how much an investment in land hinders local people's access to resources that they already use or are likely to use in the future as an adaptation option, and (ii) how much the investment is contributing to employment and human capacity-building. Investment impact assessments should be carried out by an agricultural sector coordination unit that includes the finance and justice ministries, and the activities of these units should be informed by information gathered by domestic and international non-governmental organizations (NGOs) when monitoring such investments. While foreign investment is not the only factor hindering access to land, such investment should nevertheless be assessed urgently, as it might further hamper access to land for smallholder farmers and other vulnerable actors. This is because the competition for land is between actors of unequal power. Countries such as Kenya are already focusing on how to improve access to land through a new constitution that ensures equal access to land by men and women. In addition, population pressure and the ensuing land fragmentation could be addressed by strategically developing the skills of populations to allow them to move out of agriculture.

2. Ensuring skilled agricultural manpower for innovative agricultural production systems

Currently low productivity levels of agriculture in SSA already indicate that skill deficits and changes in natural parameters will render age-long indigenous knowledge built from one generation to another inadequate. Farmers need knowledge and information on new climatic parameters in order to implement innovative production systems that are more resilient and at the same time more productive. The dissemination of existing indigenous practices from other climatic regions could also facilitate adaptation to new climatic parameters. Adaptation will need to be oriented towards making more effective use of the natural endowments of farms. This includes, for example, enhancing soil fertility by building up soil organic matter through recycling of biomass and composting, which will significantly improve soil resilience and its water retention capacity. It also includes the use of biomass and organic waste for (off-grid) energy generation.

The need for innovation offers opportunities for public-private partnerships in adaptation to climate change, as the following two examples show. First, innovative information and communication technologies (ICTs), such as short message services on mobile phones (SMS) are currently being used in SSA to disseminate market information and transfer money (Aker and Mbiti, 2010; Jack and Suri, 2011). Communication enterprises, in collaboration with universities, extension services, NGOs and other partners, could develop information services to which farmers could subscribe. Most households in rural areas in developing countries have mobile telephones, and, by improving coverage of the network, information could be disseminated to local producers at little cost; or existing information services could be extended to include innovation-related issues.

Second, successful innovation will increasingly depend on facilitating on-farm learning among farmers. This can be supported by farmer field schools and new forms of hands-on collaboration between farmers, extension workers and researchers (see also the comments of Klerkx as well as Mbuku and Kosgey in Chapter 3 of this Review). In the case of cash crops, private corporations are also promoting the development and dissemination of sustainable agricultural practices in order to respond to consumer demand and to stabilize the supply of agricultural inputs. One example is Unilever which aims at sustainable sourcing for all products by 2020, and chose tea farming in Kenya as a pioneering activity. Smallholders and the Kenyan extension service are major participants in this programme, and local production and dissemination of new knowledge is a key mechanism.

Extension services are crucial for improving agricultural productivity and for increasing the resilience of this sector to climate change. In countries such as Kenya and Malawi, enterprising farmers are now acquiring the information and knowledge they need to maintain and sustain their production themselves (Ifejika Speranza, 2010). However, in addition, local producers could be trained as extension officers recognized by the government in order to offer extension services to other farmers who lack this capacity. This could help to address many shortcomings of current government extension services, such as the limited funding and the frequent transfers of extension officers from one location to another which prevent the development of an ecological and socio-economic memory that might underpin the consolidation of development interventions. Formally trained extension officers could then focus on more specialized services such as crop-specific services (for more information, see the comment of Klerkx in chapter 3 of this Review). Finally, studies on the adoption of conservation agricultural practices show that partnerships between research, government extension services and private companies are crucial for increasing farmers' productivity.

3. Improving access to inputs

Various crop research institutions have already developed improved crop varieties that would respond to most of the impacts of climate change in Africa (e.g. tolerance to drought and higher temperatures, early maturity, higher yields, higher protein content and pest resistance) in the short term (ICRISAT, 2009). However, improved crop varieties are of no use if the farmers cannot access them due to lack of information and required additional inputs, or because they cannot afford them. Access to information about these new varieties can be improved by using communication and extension services as discussed above. Further opportunities lie in developing indigenous seed enterprises and partnerships with national agencies for rapid farmer participatory varietal testing and release, and through the provision of information to farmers, extension officers and NGO groups about new varieties. These learning experiences are also important for testing new varieties in the field and for analysing practical reasons why there might be reduced acceptance. Improving the policy environment for disseminating seeds across borders is also a strategy followed by research institutions to ensure that improved seeds reach the farmers. Harmonization of regional seed regulations in Africa is expected to improve the rates of release of new varieties, lower the costs in dealing with regulatory authorities, increase trade in improved seed varieties and, ultimately, their adoption by farmers (Minot et al., 2007).

Farmers also have limited knowledge of and access to these new crop technologies (Kijima, 2008; WARDA, 2008; ICRISAT, 2009; CIMMYT/IITA, 2011). To address these shortcomings, governments can financially support local seed breeding companies and distribute free trials to farmers on a promotional basis, after which they would have to pay for subsequent supplies. Microcredit for innovative farming will also be necessary to help overcome the high upfront costs of new management practices required for conservation farming and other integrated approaches. For an initial transition period, government subsidies may also be warranted, as in Malawi, where a Farm Input Subsidy Program (FISP) has been shown to increase maize and legume production (Chibwana et al., 2011), and has been described as a smart subsidy. However, Chibwana et al. (2011:4) also highlight the difficulty of such interventions reaching the poor as “the most vulnerable people in the Malawian communities were not the main recipients of FISP coupons”, even when intended as the target groups. The input subsidies initially led to a greater specialization in maize, and to reduced crop diversification and allocation of land to legume crops, due to a lack of legume seeds in the market. The FISP later led to increased maize and legume crop production, when farmers were provided with both improved maize and legume seeds. Chibwana et al. (2011) thus argue that while the FISP contributed to Malawian food security, it needs to be adapted to make it less prone to the unintended effects of concentrating production on one crop relative to the others, in particular, with regard to high input prices.

4. Improving knowledge about local climate changes

Knowing how the local climate is changing and is expected to change in the future as well as the associated risks is crucial for prioritizing adaptation strategies and a shift towards greater resilience. For example, Safaricom from Kenya (who revolutionized money transfer in Kenya) promoted access to information in rural Kenya through Safaricom Foundation Lifeline radio sets, which serve as a platform for radio service broadcasts by the Kenya Meteorological Department (Safaricom Foundation, 2005). Development cooperation should be aware of such innovative projects and programmes, and approach private companies to explore partnerships for their adaptation and further development. Another step is to systematically integrate climate-relevant information into existing national agricultural programmes in order to raise the awareness of decision-makers about the risks their development interventions might encounter. This will already help to integrate climate change adaptation into policies and programmes before their implementation at the local level.

5. Adopting a sectoral approach to adaptation

Agriculture is still the major driver of rural economies in developing countries; increasing resilience to climate change requires a sectoral approach rather than a narrow focus on the productivity of crops, livestock and fisheries. Such an approach would account for the inter-linkages between various land uses, with the goal of achieving multiple goals, including the protection of local livelihoods, conservation of water, forests and biodiversity, improving food security as well as contributing to renewable energy production. Integrated water resource management will be pivotal for ensuring water availability for economic, social and environmental uses under conditions of climate change. This is even more urgent as the shift towards renewable energy technologies will increase competition for water resources (hydropower versus irrigation) and for land (for food crops, biofuels, livestock, forests and biodiversity protection), and it may also exacerbate existing local conflicts over land tenure rights.

Many approaches that generate adaptation benefits and increase resilience also reduce GHG emissions, and therefore present an opportunity for an even more comprehensive mainstreaming effort that includes mitigation aspects. Therefore, new policy coordination mechanisms need to be established or improved at local, national, regional and global levels. Integrating climate-relevant information into existing national agricultural programmes may contribute to raising the awareness of decision-makers to the risks confronting their development interventions. At the local level, a landscape approach could be adopted, taking into account the interlinkages between water, forests and agricultural lands, and the fact that in most cases the same local producers who produce food also manage and use water resources and the forests.

One important objective of coordinated and integrated sectoral policies at national and local levels is to increase the incentives for more sustainable agricultural production systems at the farm level. Such production systems would reduce pressure on natural resources, such as soils and water, and would contribute to improving the provision of ecosystem services, which are essential for agricultural production and productivity. In this regard, supporting the accumulation of soil organic matter and thus increasing soil fertility is one of the most important examples of what is needed and a major challenge in SSA (for a more elaborate analysis on this issue, see the commentary of Leu in this chapter).

Commentary VIII: Yield and Yield Quality of Major Cereals Under Climate Change

Petra Högy and Andreas Fangmeier
University of Hohenheim, Institute for Landscape and Plant Ecology

Abstract

Atmospheric CO_2 enrichment may provide the benefits of higher yields, but, concomitantly, it could worsen cereal quality in terms of protein, amino acid and mineral content. Currently, almost half of the world's human population already suffers from micronutrient deficiencies, and this global health problem will further deteriorate as a result of CO_2 enrichment. On the other hand, an increase in temperature and changing precipitation patterns may reduce yield, while having a positive effect on nutritive value and processing.

Although several developments in agriculture, such as breeding and management practices, have increased yield productivity and availability of cereal-based foods over the past 50 years, more than one billion people worldwide are at risk of food insecurity today (FAO, 2009b). Food insecurity arises when people do not have access to sufficient and nutritious food to meet their dietary needs. An adequate intake of calories does not automatically ensure that the need for micronutrients has been met. In the future, climate change may represent an additionally unprecedented threat to global food security, especially for people in developing countries who depend heavily on agriculture for their livelihoods.

The main driving force behind climate change is the release of greenhouse gases (GHGs) such as carbon dioxide (CO_2) due to human activities. And this is likely to increase over the next few decades (IPCC, 2007d). By conservative estimates, the current concentration of atmospheric CO_2 of about 387 parts per million (ppm) will increase to nearly 550 ppm by 2100;[38] indeed, it is increasing faster than expected. Amid rapidly rising food demand, global atmospheric CO_2 enrichment will affect agroecosystems both directly and indirectly, resulting in changes in yield of major cereals, but potentially affecting yield quality traits as well. As cereals supply the bulk of calories for many populations in the developing world, while also constituting the primary source of both protein and micronutrients, climate change is set to exacerbate many of the problems which developing countries already have to deal with. Currently, there has been surprisingly little research specifically geared to maintaining or enhancing the productivity of agricultural ecosystems under climate change. Neither has there been much research that addresses the issue of vulnerability to climate change of other aspects of food systems such as yield quality (Richardson et al., 2009).

A. Direct effects of atmospheric CO_2 enrichment

Atmospheric CO_2 is the primary source of carbon for cereals, which is taken up by the leaf through stomata. Cereals must absorb light to enable photosynthesis to convert CO_2 into organic compounds such as carbohydrates and amino acids. Water and nutrients are usually acquired from the soil and, together with photosynthate, are used to create new plant tissues. CO_2 effects differ according to the photosynthetic pathway. Elevated CO_2 affects C_3[39] cereals by improving nitrogen use efficiency (NUE) and water use efficiency (WUE), while C_4[40] cereals are affected exclusively via impacts on WUE. Major cereals that have the C_3 photosythetic pathway include wheat, barley and rice, while maize, sorghum and sugarcane are C_4 species. In C_3 cereals, elevated CO_2 is expected to have positive physiological effects by stimulating photosynthesis, mainly by enhancing CO_2 fixation of the chloroplast enzyme RubisCO and inducing stomatal closure. As a consequence, elevated CO_2 results in shifts in biomass allocation and higher yield production (the so-called "CO_2 fertilization effect" referred to by Pritchard and Amthor, 2005). Given adequate water, the effect of CO_2 enrichment on yield performance is higher for C_3 cereals (10.2–15.7 per cent/100 ppm CO_2, Hartfield et al., 2011) than for C_4 crops (1.7 per cent/100 ppm CO_2, Hartfield et al., 2011), because C_3 photosynthesis is not saturated under ambient CO_2 levels.

On the other hand, both C_3 and C_4 cereals might benefit from elevated CO_2 under drought stress due to improvements in water use efficiency. However, the positive yield response to elevated CO_2 has often been due to more grains rather than larger grains. In addition to these effects on the quantity, it appears that CO_2 enrichment also affects the nutritional quality of C_3 cereals (Kimball, Kobayashi and Bindi, 2002). In many instances, the extra carbon is converted into carbohydrates such as starch. Consistently, the amylose content of rice grains, which is a major determinant of cooking quality, has been observed to increase under CO_2 enrichment (Conroy et al., 1994), resulting in more firmness of cooked rice grains.

A negative interaction between nitrogen status in plants and grain quality has been observed in C_3 cereals, made worse by CO_2 enrichment due to changes in leaf nitrogen metabolism. Such changes are largely the result of smaller partitioning of nitrogen in photosynthetic processes (Kimball et al., 2001). As small-grained cereals, such as barley, wheat and rice, may remobilize up to 90 per cent of the nitrogen from the vegetative plant parts during grain filling, less nitrogen investment in the plant under elevated CO_2 could be the primary cause of reduction in grain protein concentration. Although it is known that nitrogen is a key regulator of plant responses to CO_2, the changes in nitrogen metabolism are not well understood at a biochemical level. However, the nutritional value of these three cereals may deteriorate due to CO_2-induced decreases in grain protein concentration by 9.8–15.3 per cent (Taub, Miller and Allen, 2008), with serious consequences for most applications in terms of processing such as bread-making. As elevated CO_2 inhibits nitrate assimilation in C_3 cereals, it will be critical for farmers to carefully manage nitrogen fertilization in order to prevent loss of grain protein (Bloom et al., 2010).

Idso and Idso (2001), on the other hand, have argued that any effects of CO_2 enrichment on protein content in cereals could be ameliorated by increased use of nitrogen fertilizer. It is apparent that greater attention will have to be given to nitrogen management in cereals under CO_2 enrichment in order to increase production efficiency and to maintain both yields and protein concentrations in grains. However, it should be kept in mind that, especially in developing countries, the availability of nitrogen in agriculture is often insufficient to achieve adequate crop yields, and this is one of the causes of malnutrition. Moreover, CO_2-induced alterations in the composition of proteins and amino acids may also affect the nutritive value of grains and processing quality such as bread-making (Högy and Fangmeier, 2008; Högy et al., 2009). In addition, subtle imbalances in macro- and micro-element properties may occur under CO_2 enrichment, resulting in higher risk of “hidden hunger” and malnutrition (Loladze, 2002).

In rice, concentrations of iron and zinc – important for human nutrition – were seen to be lower under elevated CO_2 (Seneweera and Conroy, 1997). Similarly, Högy et al. (2009) reported a decrease in iron in wheat grains under CO_2 enrichment. These findings are vital for the important task of tackling micronutrient deficiencies of iron, zinc, copper, iodine and selenium, as the major grain crops are a critical source of these nutrients for many populations around the world (Caulfield and Black, 2004; Stoltzfus et al., 2004). Currently, almost half of the human population already suffers from micronutrient deficiencies, and this global health problem will worsen under CO_2 enrichment.

Recently, it has been reported that the nitrogen nutritional status of cereals appears to be critical, as the transporting of iron from the rhizophere into grains is dependent on various proteins and other nitrogenous components (Cakmak et al., 2010). CO_2 enrichment can have the effect of reducing the grain iron concentration by worsening the grain protein concentration, and thereby the sink strength of the grain for iron.

CO_2-induced impacts on yield quality of cereals are currently not well understood, and the available information is still inconsistent (DaMatta et al., 2010; Moretti et al., 2010). Nevertheless, it seems that macro- and micronutrient management is necessary for maintaining grain quality under CO_2 enrichment. In addition, innovations in the processing of staple crops and changes in people’s diets will be needed in a high-CO_2 world. The effects of CO_2 in terms of reducing the nutritional value of cereals would primarily impact on populations in poorer countries who are less able to compensate by eating more food and more varied diets, or possibly taking nutritional supplements. To meet the increasing demand for healthy food, and with the world’s population predicted to increase to 10.1 billion by 2100 (United Nations, 2011), it will be necessary to increase crop production. The use of cereals that can respond effectively to CO_2 enrichment while maintaining high-quality traits may be a powerful option to respond to these increased requirements.

In conclusion, elevated atmospheric CO_2 concentration will have a direct effect on major C_3 cereals, resulting in higher grain yields. However, at the same time, many qualitative compounds associated with cereals as food crops will be adversely affected in the future, notably, declines in proteins, amino acids and minerals such as iron and zinc. As mentioned earlier, these effects have been observed in grains under CO_2 enrichment, resulting in a higher risk of "hidden hunger" and malnutrition, especially in developing countries.

B. Indirect effects of rising temperatures and changes in precipitation patterns

Indirect impacts of atmospheric CO_2 enrichment on agricultural ecosystems may occur due to global warming. Global temperatures are likely to increase by at least 2°C before the end of this century. Moreover, global warming is likely to increase the frequency of heat-stress episodes. It is well known that agricultural productivity is sensitive to temperature during the growing season. As many crops are near their maximum temperature tolerance in Africa, Asia and Latin America, yields are likely to fall sharply with even small increases in temperature. Thus developing countries which face rapid population growth are at a particularly high risk of food shortages caused by temperature increases. Severall studies confirm that a 1°C rise in temperature corresponds to a roughly 10 per cent reduction in yield of major cereals such as wheat, rice and maize due to a shortening of the grain-fill duration (Battisti and Naylor, 2009; Lobell et al., 2008).

The response of cereals to temperature change has been observed to be non-linear, because of the interaction of water and heat stress (Lobell, 2007). Moreover, cereals respond differently to temperature during their life cycle, with a higher temperature optimum during their vegetative development compared with the period of reproductive development. The pollination phase of development, in particular, is one of the most sensitive to episodic temperature increase, and temperature extremes during the reproductive stage can produce some of the greatest impacts on cereal production. Floral sterility caused by elevated temperature may lower sink demands for carbohydrates and thus hinder the translocation of photosynthates from shoot (source) to grain (sink), resulting in an accumulation of dry matter in the shoot even after flowering. On the other hand, the grain size of cereals remains relatively constant and declines only slowly with increasing temperatures, until the pollination failure point.

Besides yield parameters, grain quality traits of the crops produced are also highly vulnerable to temperature. Temperatures up to the species-dependent optimum accelerate the rate of maturation, causing increases in protein content accompanied by changes in grain protein composition and dough quality characteristics, such as dough strength (Corbellini et al., 1998). Accelerated senescence leads to nitrogen remobilization from vegetative plant parts, and amino acids derived from protein degradation compensate for the temperature-induced decrease in grain filling time and the nitrogen shortage due to reduction of nitrogen uptake from soil by cereal roots. Again, the timing of stress occurrence is an important factor in determining the effect on grain protein concentration. In rice, high temperatures during grain filling were observed to increase the accumulation of all classes of storage proteins at the early filling stage, whereas they reduced the accumulation of prolamins at maturation (Lin et al., 2010). In contrast, carbohydrate synthesis in grains depends primarily on concurrent carbon fixation during grain filling; thus grain starch declined due to shortened duration of starch accumulation or due to the inhibition of key enzymes involved in starch synthesis.

Changes in precipitation (both amount and frequency) can also have devastating impacts on agriculture, with grave consequences for human nutrition and global health. Since water status is important for mineral mobilization, water deficiency may reduce the uptake of iron, zinc and copper from the soil, resulting in decreased concentrations of these minerals in cereal grains such as maize (Oktem, 2008). Micronutrient malnutrition has enormous socio-economic impacts, such as increased mortality and morbidity, impaired growth, development and learning capacity in infants and children as well as loss of working capabilities of adults. This in turn undermines economic growth and perpetuates poverty (World Bank, 2006; WHO, 2002). Climate change is expected to alter the timing and quantity of water available for agriculture while increasing the needs of crops for water as temperatures rise.

Today, many farmers around the world are already experiencing less predictable rainfall and temperatures as well as extreme weather events. As different cultivars respond differently to climatic factors and uncertainties exist about future conditions for cereal production, new varieties of cultivars need to be developed with traits such as heat and drought resistance.

Overall, it can be concluded that indirect impacts due to atmospheric CO_2 enrichment, such as temperature increases and changes in precipitation patterns, may reduce the grain yield of major cereals. On the other hand, protein concentration may increase under rising temperatures, resulting in a higher nutritive value of grains. However, decreases in accumulation of starch and minerals such as iron, zinc and copper in major cereals may affect the nutritional quality of the end-product and food security, as well as the use of those cereals for processing in the future.

C. Outlook

CO_2-induced effects on grain yield and crop quality will likely differ substantially among individual cultivars and species under varying regional climatic conditions. As high CO_2 concentrations cause alterations in evapotranspiration, this may also result in feedback on water magagement and droughts. Water conservation may allow extension of the growth period when water is limited. Less information is available on the interactive effects of climate variability and CO_2 enrichment on the efficiency of resource use (e.g. water, nutrients) and its consequences for yield quantity and quality of major cereals. Higher temperatures and variations in precipitation might reduce the positive CO_2-induced impacts on cereal performance.

With regard to the availability of adequate food supply in the future, a major task is therefore to identify the impacts of climate change on yield quality in terms of nutritive value and end-use processing. Adaptation of cereal production and processing to an increasingly variable climate is thus of the utmost importance, particularly in developing countries, to ensure not only sufficient supplies of cereals, but also their nutritive quality. In order to assure food security in the future, it is vitally important to understand the complex relationships between global environmental changes, farming practices, diet and human health.

Commentary IX: Comparative Analysis of Organic and Non-Organic Farming Systems: A Critical Assessment of Farm Profitability

Noémi Nemes
FAO

Abstract

An analysis of over 50 economic studies demonstrates that, in the majority of cases, organic systems are more profitable than non-organic systems. Higher market prices and premiums, or lower production costs, or a combination of the two generally result in higher relative profits from organic agriculture in developed countries. The same conclusion can be drawn from studies in developing countries, but there, higher yields combined with high premiums are the underlying causes of their relatively greater profitability.

Organic agriculture has triggered a controversial debate over the past few decades, largely because it exposes the true costs and darker sides of chemical-intensive industrial farming systems. There is now a strong body of evidence to prove that organic farming is more environmentally friendly: potential benefits arise from, for example, improved soil fertility, organic matter content and biological activity, better soil structure and less susceptibility to erosion, reduced pollution from nutrient leaching and pesticides, and improved plant and animal biodiversity (Kasperczyk and Knickel, 2006). However, it is not clear whether organic agriculture could be economically attractive enough to trigger its widespread adoption. If organic farming offers better environmental quality and healthier foods but not sufficient economic returns to the majority of farmers, it will obviously remain a luxury form of food production viable for only a very small fraction of farmers. However, the continued growth of organically managed lands worldwide, especially in developing countries, does not support this hypothesis.

A. Comparing the economics of organic versus non-organic farming

There are well over 100 studies that compare the relative profitability of organic versus non-organic agriculture. However, there are fewer long-term comparative studies that analyse the development of profits from each of these systems. Regrettably, the geographical distribution of these studies tends to concentrate on developed countries (mainly the United States) and on certain cash crops (e.g. corn, soy, wheat). For the purpose of this analysis, only studies using data from certified organic farms were considered, covering a minimum period of three years (for developed countries) after conversion and undertaken after 1980. Due to the lack of long-term economic studies in developing countries, studies covering one and two years were included from these countries. Studies that evaluated yields and certain production costs but not profits were not considered.

Several factors complicate the task of comparing economic studies across space and time, such as different costs of living and purchasing power, different interpretations of labour costs, and the changing economic and political environment. Moreover, methodological choice, the time period analysed and the selection procedure for comparable conventional farms have a considerable bearing on profitability. Similarly, the extent of the economic assessment can vary across studies, with some studies focusing merely on the farm level, while others broaden the picture to the level of society, and this can lead to different outcomes. Depending on this choice, opportunity costs and externalities are either included (society level), or, as in most cases, excluded (farm level). When looking at profitability studies, a correct interpretation of the data is crucial: overall comparisons cannot be made, for example between case studies and field experiments, between developed- and developing-country results, and between studies with a very good data base and studies based on farmers' opinions.

B. Yields

Evidence from the more than 50 studies analysed showed that yields in well-established organic farms in developed countries are usually lower than those from conventional farms, to varying degrees. Most European studies including those of organic cereal, vegetable and mixed farming systems showed that they produced somewhat lower yields (BMELF, 1991–1998; FAT, 1997; Offermann and Nieberg, 2000), whereas milk yields most often showed similar results when measured in litres per cow (Younie et al., 1990; FAT, 1993; Offermann and Nieberg, 2000). On the other hand, the majority of long-term studies involving soy-corn rotation in the United States showed that organic yields, on average, were not significantly different (Chase and Duffy, 1991; Hanson, Lichtenberg and Peters, 1997; Drinkwater, Wagoner and Sarrantonio, 1998; Delate et al., 2003; Pimentel et al., 2005). Despite lower soy yields from organic farms in some other United States studies (Mahoney et al., 2004; Chase, 2008; McBride and Greene, 2009), high premiums (McBride and Greene, 2009) or lower production costs (Mahoney et al., 2004; Chase, 2008) rendered all organic systems more profitable.

Several of the United States studies investigated drier areas as well and found higher yields in the organic systems (Stanhill, 1990; Diebel, Williams and Llewelyn, 1995; Dobbs and Smolik, 1996; Hanson, Lichtenberg and Peters, 1997; Pimentel et al., 2005), suggesting that those systems are more resistant to drought. Similarly, studies in developing countries showed that organic yields were generally higher under normal or favourable conditions (IFAD, 2003; Raj et al., 2005; Gibbon and Bolwig, 2007; Setboonsarng, Yeung and Cai, 2006), and significantly higher under less favorable conditions (Mendoza, 2002). Overall, the majority of economic studies in developing countries showed higher yields from organic production, whereas not one study on developed countries showed higher yields from organic compared with conventional.

When converting to organic agriculture, a paradigm shift must take place, from the high external input packages for treating problems to the use of preventive management and intensive knowledge inputs. Yields are not a characteristic of a production system per se; they depend very much on farm management. Although organic produce generally yields less, yield losses can be mitigated to a certain

Box 2: Difficulties in analysing yields from comparative studies

- **Object of comparison (commodity or whole farm-based).** Some authors only look at yields of one or two cash crops separately (Chase and Duffy, 1991; Dobbs and Smolik, 1996: studies from developing countries), whereas others also evaluate average yields of the whole rotation (Hanson et al., 1997; Chase, 2008) and of intercrops (Eyhorn, Ramakrishnan and Mäder, 2007). The latter is more relevant, although more complex for obtaining meaningful results.
- **Unit of comparison (per ha or product).** Some studies evaluate cow yield per hectare (which is usually lower in organic, due to lower stocking densities), whereas others evaluate cow yield per animal (which often provides similar results), and this makes comparisons difficult.
- **Different varieties.** Varieties bred for intensive external input conditions are seldom suitable for low external input systems. Organic systems, especially in developing countries, often use local breeds and varieties which have lower yields, but which are more adapted to low external input conditions in that they require less nutrients and water inputs or have higher pest/disease resistance. However, authors generally do not specify that differences in yields may be due to different varieties.
- **Different growth periods.** Using different varieties also influences the economics of the whole rotation system; for example, many organic farmers in India use desi cotton, which is a whole-season crop, thus after harvest farmers cannot grow anything else in the rotation. Most conventional farmers grow hybrid varieties under irrigation (in the studies analysed), which enables the cultivation of two or three crops per year (Jackson, 2008).
- **Managerial background.** The intensity of previously managed conventional farms is a significant factor contributing to the yield decreases during and after conversion to organic. Yet often the background of organic farms is not clear from the studies, even though it influences the comparative baseline.

extent by proper soil management, shade trees (such as in coffee cultivation), timely removal of diseased plants, and a healthy balance between pests and natural enemies as biological controls (Van der Vossen, 2005). Nevertheless, although an important element of profitability, yields alone do not necessarily indicate profitability.

C. Production costs

In farm economics, there is no absolute definition of what has to be considered as variable costs or as fixed costs; it depends on the aim of the research. Some studies consider only variable costs to calculate gross margins (Younie, Hamilton and Nevison, 1990), whereas others include fixed costs (Wynen, 2001; Gibbon and Bolwig, 2007), and yet others do not differentiate between the two types of costs (Olson and Mahoney, 1999; Delate et al., 2003). By definition, fixed costs are part of the total farm costs that do not vary significantly with the volume of output and can only be changed in the long run, whereas variable costs are those that vary directly with the volume of output. The differentiation between variable and fixed costs is only important when gross margins are calculated, as fixed costs are not accounted for in those margins. However, fixed costs are crucial for farm profitability. During conversion, for instance, several substantial investments have to be made (e.g. new animal-friendly housing system, new orchard varieties that can better withstand bio-physical stress) that are often counted as fixed costs, and for many farmers these costs are the determining factor as to whether converting to organic may be profitable or not. Even though most studies make the distinction between the two types of costs, they may not specify which costs are covered by each of them. Mentioning merely variable and fixed costs does not allow for the appreciation of the variables used, and thus for proper comparisons.

An even more complicated issue is the inclusion of labour costs: some comparisons omit labour costs from the total calculation of net revenues (e.g. Hanson, Lichtenberg and Peters, 1997; Delate et al., 2003), while most include hired labour in the variable costs (Wynen, 2001; Eyhorn, Ramakrishnan and Mäder, 2007; Gibbon and Bolwig, 2007; Chase, 2008); some count (hired) labour costs as fixed costs thus omitting them from gross margin results (FAT, 1993; BMELF, 1994); and yet others count family labour as an opportunity cost or leave this out completely (as in most studies of developing countries). Another approach, used by Wynen (2001), for instance, counts hired labour as a variable cost and family labour as a fixed cost. Very often in developing countries, only cash costs are included and non-cash costs (e.g. own labour and seeds) are excluded. Regardless of whether labour costs are treated under fixed and/or variable costs, the most important aspect is that they are treated consistently within the case study and are not overlooked.

From the analysis of studies, it follows that even if the different cost elements were standardized, variations among production costs would occur due to the unique character of the operations and factors beyond the control of the farmers: for example, machinery costs depend also on age, size and use, irrigation costs are subject to variations in rainfall, temperature and efficiency of irrigation systems, and labour costs depend on wage rates, working conditions and efficiency of the workers. This being said, production costs tend to be lower in established organic systems (e.g. Helmers, Langemeier and Atwood, 1986; Hanson, Lichtenberg and Peters, 1997; Olson and Mahoney, 1999; Delate et al., 2003; Mendoza, 2002; Eyhorn, Ramakrishnan and Mäder, 2007). In most of the European studies analysed by Offermann and Nieberg in 2000, total costs incurred by organic farms were, on average, slightly lower than those incurred by comparable conventional farms. While variable costs were generally significantly lower (60–70 per cent) in the organic systems, their fixed costs were up to 45 per cent higher than those of the conventional reference group in several countries. The few cases with significantly higher production costs in organic farms were the ones focusing on vegetable production or those in developing countries.

All analysed studies relied on relatively cheap input costs (based on cheap fossil fuel) that have been varying tremendously over the past few years. Input costs are bound to increase in the long run: global nitrogen fertilizer prices surged by 160 per cent during the first quarter of 2008, and fossil-fuel-based agricultural inputs (a substantial proportion of production costs) will sooner or later substantially affect farming systems that rely on the intensive use of synthetic fertilizers and pesticides. In the case of organic agriculture, oil-based inputs negatively affect production costs where plastic mulch is used, and more generally when the system is mechanized.

D. Overall profitability

Over 50 studies were analysed in terms of their research on farm profitability, and although methodological differences prevented us from comparing them systematically, the similarities between the studies from many countries and contexts allowed us to draw some general conclusions. Profitability certainly depends on the choice of crop, which of course is determined partly by environmental conditions and partly by the demand for products and by the availability of government programmes that support the cultivation of particular crops. A comparison of relative profitability depends largely on the kind of comparison group selected. Thus, farm size, farm type and location are important factors in selecting the suitable candidate farms for comparison. Price premiums also seem to be a crucial factor contributing to the good economic performance of organic systems, and in most cases they make organic farms more profitable. However, at least a dozen studies showed that price premiums are not always necessary for organic systems to be more profitable than conventional systems. If higher prices are not available to compensate for possible losses of organic yields, financial profitability will depend entirely on achieving cost reductions.

Overall, the compiled data suggest that organic agriculture is economically more profitable: net returns, taking total costs into account, most often proved to be higher in organic systems. There were wide variations among yields and production costs, but either higher market prices and premiums, or lower production costs, or a combination of these two generally resulted in higher relative profits from organic agriculture in developed countries. The same conclusion can be drawn from studies in developing countries, but there, higher yields combined with high premiums seemed to be the underlying reasons for higher relative profitability.

Establishing organic markets for staple crops (e.g. organic soybeans, wheat, chillies) that are part of a rotation offers considerable potential to further improve the profitability of organic farms in developing countries. If these crops could be sold at a premium price, the revenues of organic farms would further increase. In developed countries, a further reduction in production costs (energy, fuel, feed) and the use of better varieties (e.g. in terms of resistance and yield) could result in an increase in the relative profitability of organic farms.

E. The need for fair economic comparisons

Organic systems are generally more profitable despite unfair competition in the marketplace due to current government subsidy schemes for conventional production, unequal availability of research and extension services, and the failure of market prices of conventional foods to capture the real environmental, social and health externalities. Existing economic comparisons are therefore heavily biased in favour of conventional farming. There is an urgent need to direct much more research and investments into extension services to support organic agriculture, and shift the bulk of public support from polluting activities to sustainable practices to give an equal footing to organic farming systems. In addition, comparative studies need to take into account the differences in external costs and benefits so as to capture the

Box 3: Profitability of organic cotton production

An Indo-Swiss research team compared agronomic data of 60 organic and 60 conventional farms over two years (Eyhorn, Ramakrishnan and Mäder, 2007) and came to the conclusion that organic farming of cotton was more profitable: variable production costs were 13–20 per cent lower and costs of inputs were 40 per cent lower, yet yields were 4–6 per cent higher in the two years, and, as a result, gross margins for cotton were 30-43 per cent higher. Although there was no price premium for the crops grown in rotation with cotton, organic farms earned 10–20 per cent higher incomes than conventional farms.

In an Indian survey of 125 organic cotton farmers, 95 per cent of respondents saw their agricultural income increase by 17 per cent, on average, after adopting organic agricultural practices, which most of them attributed mainly to reduced costs of production and higher sales prices (MacDonald, 2008). Similarly, in the Indian state of Andhra Pradesh, Raj et al. (2005) found that growing organic cotton was much more profitable than growing conventional cotton (income was + $13 per acre on organic compared with -$30 per acre on conventional farms). In conclusion, all studies found organic cotton farming to be more profitable than conventional.

Box 4: Examples of environmental costs

A study by Pretty et al. (2000) estimated the annual external costs of agriculture in the United Kingdom in 1996 at £2.34 billion ($3.65 billion), equivalent to £208/ha ($324/ha) of arable and permanent pasture. This was 89 per cent of the average net farm income for 1996. Significant costs arose from the contamination of drinking water with pesticides, nitrate and phosphate, from damage to wildlife, habitats, hedgerows, from GHG emissions from soil erosion and organic carbon losses, from food poisoning and from BSE. Another study, which calculated the external costs of agriculture in the United States, including damage to water sources, to soil and air, to wildlife and ecosystem biodiversity and to human health, estimated the costs to range between $5.7 billion and $16.9 billion annually, or $29–$96/ha of cropland (Tegtmeier and Duffy, 2004). These studies only estimated externalities that gave rise to financial costs, thus they are likely to have underestimated the total negative impacts arising from the intensive use of agrochemicals.

real and multiple profits of the respective systems of agriculture.

1. Government support

National or regional agricultural programmes and subsidies are mostly geared towards supporting large-scale agriculture that makes intensive use of chemical inputs, which artificially lowers the price of conventional products. Painter (1991) compared net returns of organic and conventional farms at the end of the 1980s and found that the average governmental subsidy per hectare was 38 per cent higher for conventional production. Researchers in the 1990s also found that conventional systems benefited more from government subsidies than organic ones (Diebel, Williams and Llewelyn, 1995; Smolik, Dobbs and Rickerl, 1995). If subsidies were expanded to support long-term aspects of agricultural productivity, such as soil-building grass and legume crops, the profitability of organic farming would be even higher.

While organic farms in Europe receive considerable support from the EU's agri-environmental programmes, the design of the first pillar of the Common Agricultural Policy (CAP) put organic farming at a disadvantage in the past. The 2003 CAP reform changed this situation, particularly by decoupling direct payments. However, the results of a survey showed that only 11 per cent of organic farmers thought that decoupling had had a positive impact on their profits (Sanders, Offermann and Nieberg, 2008). There is much debate on whether the current levels of organic support are appropriate. Nevertheless, it is clear that a sharp redirection of public support from polluting activities to sustainable practices is necessary, both in developed and developing countries. Subsidies should encourage positive externalities, while advisory and institutional mechanisms, legal measures and economic instruments should correct negative externalities.

2. Research and extension

The achievements of conventional farming systems are based on several decades of intensive research and support, whereas organic research is still in its infancy. Conventional farmers often have better access to information from extension services and university researchers. Organic farmers, on the other hand, need more time and greater managerial efforts and skills to acquire the necessary knowledge on such matters as organic practices, prices and marketing opportunities. Both yield levels and gross margins of rotation crops would probably increase if extension services also provided training and advice on managing these crops organically (Eyhorn, Ramakrishnan and Mäder, 2007). Thus, comparisons of yield and farm economics between conventional and organic can be considered unfair as long as the latter do not benefit from similar research and extension service support that are directed to conventional agriculture.

3. Externalities

The profitability of a farming system must balance economic costs against environmental, social and health costs, as these costs have delayed impacts and indirect effects on farm economics. At present, comparative economic studies of the two farming systems only consider direct economic inputs and outputs in the equation, and broadly overlook the environmental, social and health costs. Accounting for externalities, such as costs associated with runoff, spills, depletion of natural resources and health costs to farmers exposed to pesticides, are lacking. Yet, generally, organic delivers more public goods such as environmental and health benefits. Taking the differences in external costs and benefits into account would give a more accurate profitability picture of the different systems.

In these completely distorted markets that fail to pro-vide a level playing field between organic and conventional agriculture, subsidies are one way of helping organic farmers to continue with environmentally friendly farming practices. Price supports could take the form of compensation that rewards farmers for the ecosystem and societal services (e.g. landscape) they are performing for the common good. Both external costs and benefits could be quantified in economic terms (e.g. pollution abatement costs), and thus could be taken into account in comparative studies. This would mean a redirection of economic thinking, which would better reflect the true cost of farming practices and, hopefully, lead to the reformulation of policies so that they no longer support polluting activities, but instead correct negative externalities as far as possible.

Commentary X: Strengthening Resilience of Farming Systems: A Prerequisite for Sustainable Agricultural Production

Miguel A Altieri, University of California, Berkeley, and
Parviz Koohafkan, FAO

Abstract

Traditional farming systems have enabled farmers to generate sustained yields to meet their subsistence needs in the context of climatic variability. Part of this performance is linked to the high levels of agrobiodiversity exhibited by traditional agroecosystems. Strategies to enhance diversity in agroecosystems include support to family agriculture and to smallholders, and dynamic conservation of globally important agricultural heritage systems. Diversification is therefore an important farm strategy for managing production risk in farming systems. Strategies to restore diversity in modern farming systems include promoting seed diversity, crop rotations, cover crops, intercropping and crop/livestock mixing. Diversified farming systems managed with modern equipment allow complementary interactions that boost yields with low inputs, thus increasing profits, and, given the diversity of crops, minimizing production risks.

Today, a major challenge facing humanity is how to achieve a sustainable agriculture that provides sufficient food and ecosystem services for present and future generations in an era of climate change, rising fuel costs, social tensions caused by food price hikes, financial instability and accelerating environmental degradation. The challenge is compounded by the fact that the majority of the world's arable land is under "modern" monoculture systems of maize, soybean, rice, cotton and others, which, due to their ecological homogeneity, are particularly vulnerable to climate change as well as biotic stresses. Little has been done to enhance the adaptability of industrial agroecosystems to changing patterns of precipitation, temperatures and extreme weather events (Rosenzweig and Hillel, 2008). This realization has led many experts to suggest that the use of ecologically based management strategies may represent a robust means of increasing the productivity, sustainability and resilience of agricultural production while reducing its undesirable socio-environmental impacts (Altieri, 2002; de Schutter, 2010b).

Observations of agricultural performance after extreme climatic events during the past two decades have revealed that resilience to those events is closely linked to the level of on-farm biodiversity (Lin, 2011). Most scientists agree that a basic attribute of agricultural sustainability is the maintenance of agroecosystem diversity in the form of spatial and temporal arrangements of crops, trees, animals and associated biota. Increasingly, research suggests that agroecosystem performance and stability is largely dependent on the level of plant and animal biodiversity present in the system and its surrounding environment (Altieri and Nicholls, 2004). Biodiversity performs a variety of ecological services beyond the production of food, including recycling of nutrients, regulation of microclimate and of local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals. Because biodiversity-mediated renewal processes and ecological services are largely biological, their continued functioning depends upon the maintenance of biological integrity and diversity in agroecosystems. In general, natural ecosystems appear to be more stable and less subject to fluctuations in yield and in the populations of organisms making up the community. Ecosystems with higher diversity are more stable because they exhibit greater resistance, or the ability to avoid or withstand disturbances, and greater resilience, or the ability to recover following disturbances.

Biodiversity enhances ecosystem functions because those components that appear redundant at one point in time may become important when some environmental change occurs. What is important is that when environmental change occurs, the redundancies of the system enable continued ecosystem functioning and provisioning of services (Vandermeer et al., 1998).

Traditional farming systems, which still persist in many developing countries, offer a wide array of management options and designs that enhance functional biodiversity in crop fields, and consequently support the resilience of agroecosystems (Uphoff, 2002b; Toledo and Barrera-Bassals, 2009). The myriad of traditional systems are a globally important, ingenious agricultural heritage which reflects the value of the diversity of agricultural systems that are adapted to different environments. They tell a fascinating story of the ability and ingenuity of humans to adjust and adapt to the vagaries of a changing physical and material environment from generation to generation. Whether recognized or not by the scientific community, this ancestral knowledge constitutes the foundation for actual and future agricultural innovations and technologies. The new models of agriculture that humanity will need in the immediate future should include forms of farming that are more ecological, biodiverse, local, sustainable and socially just. Therefore, they will necessarily have to be rooted in the ecological rationale of traditional small-scale agriculture, which represents long-established, successful and adaptive forms of agriculture (Koohafkan and Altieri, 2010).

A. Small farms as models of resilience

In continuously coping with extreme weather events and climatic variability through centuries, farmers living in harsh environments in Africa, Asia and Latin America have developed and/or inherited complex farming systems managed in ingenious ways. These have allowed small farming families to meet their subsistence needs in the midst of environmental variability without depending much on modern agricultural technologies (Denevan, 1995). The continued existence of millions of hectares under traditional farming is living proof of a successful indigenous agricultural strategy, which is a tribute to the “creativity” of small farmers throughout the developing world (Wilken, 1987). Today, well into the first decade of the twenty-first century, millions of smallholders, family farmers and indigenous people are continuing to practice resource-conserving farming. Such traditional systems are testament to the remarkable resilience of agroecosystems to continuous environmental and economic change, which, despite changes, continue to contribute substantially to agrobiodiversity conservation and food security at local, regional and national levels (Netting, 1993).

However, climate change can pose serious problems for the majority of the 370 million of the world’s poorest, who live in areas often located in arid or semi-arid zones, and in ecologically vulnerable mountains and hills (Conway, 1997). In many countries, more and more people, particularly those at lower income levels, are now forced to live in marginal areas (i.e. floodplains, exposed hillsides, arid or semi-arid lands), where they are at risk from the negative impacts of climate variability. Even minor changes in climate can have disastrous impacts on the lives and livelihoods of these vulnerable groups. The implications for food security could be very profound, especially for subsistence farmers living in remote and fragile environments that are likely to produce very low yields. These farmers depend on crops that could be badly affected, such as maize, beans, potatoes and rice. Despite the serious implications of predictions, data represent only a broad brush approximation of the effects of climate change on small-scale agriculture. In many cases those data ignore the adaptive capacity of small farmers who use several agroecological strategies and socially mediated solidarity networks to cope with and even prepare for extreme climatic variability (Altieri and Koohafkan, 2008).

Three studies assessing agricultural performance after extreme climatic events reveal the close link between enhanced agro-biodiversity and resilience to extreme weather events. A survey conducted in Central American hillsides after Hurricane Mitch showed that farmers engaged in diversification practices, such as cover crops, intercropping and agroforestry, suffered less damage than their neighbours who practiced conventional monoculture. The survey, spearheaded by the Campesino a Campesino movement, mobilized 100 farmer-technician teams to carry out paired observations of specific agroecological indicators on 1,804 neighbouring sustainable and conventional farms. The study spanned 360 communities and 24 departments in Guatemala, Honduras and Nicaragua. It found that plots where farmers adopted sustainable farming practices had

20 to 40 per cent more topsoil, greater soil moisture and less erosion, and experienced smaller economic losses than their conventional neighbours (Holt-Giménez, 2002). Similarly in Sotonusco, Chiapas, coffee systems exhibiting high levels of vegetation complexity and plant diversity suffered less damage from Hurricane Stan than more simplified coffee systems (Philpott et al., 2008). And in Cuba, 40 days after Hurricane Ike hit the country in 2008, researchers conducting a farm survey in the provinces of Holguin and Las Tunas found that diversified farms exhibited losses of 50 per cent compared to 90 or 100 per cent in neighbouring monoculture farms. Likewise, agroecologically managed farms showed a faster recovery of productivity (80–90 per cent 40 days after the hurricane) than monoculture farms (Rosset et al., 2011). All three studies emphasize the importance of enhancing plant diversity and complexity in farming systems to reduce vulnerability to extreme climatic events. Since many peasants commonly manage polycultures and/or agroforestry systems, their knowledge and practices could provide a key source of information on adaptive capacity centred on the selective, experimental and resilient capabilities of those farmers in dealing with climatic change.

Given the resilience of diversified small farming systems, understanding the agroecological features of traditional agroecosystems is an urgent matter, as this can serve as the foundation for the design of agricultural systems that are resilient to climate change (Altieri and Koohafkan, 2008).

B. Restoring agrobiodiversity in modern agroecosystems

Since the modernization of agriculture, farmers and researchers have been faced with a major ecological dilemma arising from the homogenization of agricultural systems, namely the increased vulnerability of crops to pests and diseases, and now to climatic variability. Both these phenomena can be devastating in genetically uniform, large-scale, monoculture conditions. Monocultures may offer short-term economic advantages to farmers, but in the long term they do not represent an ecological optimum. Rather, the drastic narrowing of cultivated plant diversity has put the world's food production in greater peril (Perfecto, Vandermeer and Wright, 2009).

Given the new climate change scenarios predicted over the next two decades or so by some scientists (e.g. Rosenzweig and Hillel, 2008), the search for practical steps to break the monoculture nature of modern agroecosystems, and thus reduce their ecological vulnerability, is imperative. As traditional farmers have demonstrated with farming systems that stood the test of time, restoring agricultural biodiversity at the field and landscape level is key to enhancing resilience. Greater diversity of species is probably needed to reduce temporal variability of ecosystem processes in changing environments. The most obvious advantage of diversification is reduced risk of total crop failure due to invasions of unwanted species and/or climatic variability, as larger numbers of species reduce temporal variability in ecosystem processes in changing environments (Loreau et al., 2011). Studies conducted in grassland systems suggest that there are no simple links between species diversity and ecosystem stability. Experiments conducted in grassland plots conclude that functionally different roles represented by plants are at least as important as the total number of species in determining processes and services in ecosystems (Tilman et al., 2001a). This latest finding has practical implications for agroecosystem management. If it is easier to mimic specific ecosystem processes rather than attempting to duplicate all the complexity of nature, then the focus should be placed on incorporating a particular biodiversity component that plays a specific role, such as plants that fix nitrogen, provide cover for soil protection or harbour resources for natural enemies of insect pests.

Contemporary notions of modern mechanized farming emphasize the necessity of monocultures. There is little question, however, that given sufficient motivation, appropriate technology could be developed to mechanize multiple cropping systems (Horwith, 1985). Simpler diversification schemes based on 2 or 3 plant species may be more amenable to large-scale farmers and can be managed using modern equipment. One such scheme is strip intercropping, which involves the production of more than one crop in strips that are narrow enough for the crops to interact, yet wide enough to permit independent cultivation. Agronomically beneficial strip intercropping systems have usually included corn or sorghum, which readily respond to higher light intensities (Francis et al., 1986). Studies with corn and soybean strips 4 to 12 rows wide demonstrated increased corn yields (5 to 26 per cent higher) and decreased soybean yields (8.5 to 33 per cent lower) as strips got narrower. Alternating corn and alfalfa strips provided greater gross returns than single crops. Strips of 20 ft. (approximately 6.1 meters) width were the most advantageous, with substantially higher economic returns than the single crops (West and Griffith, 1992). This advantage is critical for farmers who have debt-to-asset ratios of 40 per cent or higher ($40 of debt for every $100 of assets). Such a level has already been reached by more than 11–16 per cent of farmers in the mid-western United States who desperately need to cut costs of production by adopting diversification strategies.

Legumes intercropped with cereals is a key diversification strategy, not only because of their provision of nitrogen, but also because the mixtures enhance soil cover, smother weeds and increase nutrients (e.g. potassium, calcium and magnesium) in the soil through the addition of biomass and residues to the soil. Such intercropping systems also increase soil microbial diversity such as vesicular arbuscular mycorrhizae (VAM) fungi which facilitate phosphorous transfer to the crops (Machado, 2009). In the case of adverse weather conditions, such as a delay in the onset of rains and/or failure of rains for a few days, weeks or during the cropping period, an intercropping system provides the advantage that at least one crop will survive to give economic yields, thereby serving as the necessary insurance against unpredictable weather. Polycultures exhibit greater yield stability and lower productivity declines during a drought than monocultures. This was well demonstrated by Natarajan and Willey (1986) who examined the effects of drought on polycultures by manipulating water stress on intercrops of sorghum (*Sorghum bicolor*) and peanut (*Arachis* spp.), millet (*Panicum* spp.) and peanut, and sorghum and millet. All the intercrops consistently provided greater yields at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the cropping season. Interestingly, the rate of over-yielding actually increased with water stress, such that the relative differences in productivity between monocultures and polycultures became more accentuated as stress increased.

No-till row crop production is also promising, given its soil conservation and improvement potential, but it is highly dependent on herbicides. However, there are some organic farmers who practice it without synthetic herbicides. A breakthrough occurred with the discovery that certain winter annual cover crops, notably cereal rye and hairy vetch, can be killed by mowing at a sufficiently late stage in their development and cutting close to the ground. These plants generally do not re-grow significantly, and the clippings form an *in situ* mulch through which vegetables can be transplanted with no or minimal tillage. The mulch hinders weed seed germination and seedling emergence, often for several weeks. As they decompose, many cover crop residues can release allelopathic compounds that may suppress weed growth (Moyer, 2010) by means of phytotoxic substances that are passively liberated through decomposition of plant residues. There are several green manure species that have a phytotoxic effect which is usually sufficient to delay the onset of weed growth until after the crop's minimum weed-free period. This makes post-plant cultivation, herbicides or hand weeding unnecessary, yet exhibits acceptable crop yields. Tomatoes and some late-spring brassica plantings perform especially well, and some large-seeded crops such as maize and beans can be successfully direct-sown into cover crop residues. Not only can cover crops planted in no-till fields fix nitrogen in the short term; they can also reduce soil erosion and mitigate the effects of drought in the long term, as the mulch conserves soil moisture. Cover crops build vertical soil structure as they promote deep macropores in the soil, which allow more water to penetrate during the winter months and thus improve soil water storage.

C. Conclusions

There is general agreement at the international level on the urgent need to promote a new agricultural production paradigm in order to ensure the production of abundant, healthy and affordable food for an increasing human population. This challenge will need to be met with a shrinking arable land base, with less and more expensive petroleum, increasingly limited supplies of water and nitrogen, and at a time of rapidly changing climate, social tensions and economic uncertainty (IAASTD, 2009a). The only agricultural system that will be able to cope with future challenges is one that will exhibit high levels of diversity and resilience while delivering reasonable yields and ecosystem services. Many traditional farming systems still prevalent in developing countries can serve as models of sustainability and resilience.

Resilience in agricultural systems is a function of the level of diversity within the agricultural ecosystem. It is therefore essential that strategies for an adaptive response to climate change focus on breaking away from the monoculture nature of modern agroecosystems. Small changes in the management of industrial systems, such as intercropping and/or use of rotational cover cropping in no-till systems, can substantially enhance the adaptive capacity of cropping systems. Weather extremes, including local drought and flooding, are predicted to become more common as a result of rapid climate change. Environmentally responsible water management will therefore have to be a critical part of sustainable agriculture in the future. Agroecological strategies for conserving water include choosing water-efficient crops, resource-conserving crop rotations, enhancing soil organic matter and intercropping systems.

Commentary XI: Democratizing Control of Agriculture to Meet the Needs of the Twenty-first Century

Marcia Ishii-Eiteman
Pesticide Action Network North America

Abstract

Powerful commercial interests and lack of political resolve hamper the establishment and implementation of policies to advance sustainable and equitable development. To accomplish the deep-seated change required to overcome these impediments, decisive and coordinated action among public and private sector actors and civil society is needed. Priorities for action should include:

- Curtailing corporate concentration in the food system, and increasing market access and competitiveness of small and medium-scale farmers to improve food and livelihood security;
- Reducing the undue influence of large transnational corporations over public policy, research and trade agendas; and
- Strengthening the role of civil society – including farmers' organizations – in designing and implementing policies and in guiding partnerships dedicated to public interest outcomes.

Policies and practices that meet global food needs sustainably and equitably and support a shift towards ecological farming systems can conserve biodiversity, water and energy and reduce greenhouse gas (GHG) emissions (IAASTD, 2009a and b; De Schutter, 2011; UNEP, 2011). Policy options to drive this transformation of agriculture have been described by the United Nations-sponsored International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009a and b; box A). Likewise, the economic viability, environmental urgency and human rights imperative of implementing such a transformation have been well established (De Schutter, 2008; UNCTAD/UNEP, 2008; FAO 2012c; UNEP 2011).

Despite the availability of robust policy options, powerful commercial interests, weak or captured public sector actors and lack of political will continue to hamper the establishment and meaningful implementation of these progressive options. The constraints – outlined below – are systemic; a few superficial changes will not make a significant enough difference to achieve concrete outcomes. Rather, highly targeted and strategic interventions are needed that tackle the core of the problem and democratize control over agriculture.

A. Constraints on the transformation of agriculture

1. Market failures and the need for full cost accounting

A fundamental failure of global markets today is the lack of price signals that incorporate the full array of health, energy and environmental costs associated with agriculture. Consequently, policymakers base their decisions on inaccurate forecasts of the potential and actual costs. Full cost accounting measures, such as national "green accounts" or "total material flow estimates" are good economic practices that more accurately reflect the true costs of food and agricultural industries, and can consequently better inform policy decisions. Sweden, for example, established a national policy to transition towards organic farming based largely on the findings of a full cost analysis of the climate-related, energy, water, environmental and other ecosystem service costs embedded in its "foodshed" (Johansson, 2008).

2. Corporate concentration in food and agriculture

In North America, growing market concentration in multiple agricultural activities, coupled with successive rounds of deregulation, have led to

Box 5: Policy options to support a transition to sustainable agriculture

As identified by the IAASTD (2009a and b), promising policy options to advance sustainable and equitable development goals include:

- Strengthening the small-scale farm sector, in particular farmers', women's, indigenous and other community-based organizations, and increasing public investment in rural areas;
- Building local and national capacity in biodiverse, ecologically resilient farming to cope with increasing environmental stresses;
- Increasing local participation and leadership in agricultural research, direction-setting, policy-formation and decision-making processes;
- Revitalizing local and regional rural economies and food systems, and more closely regulating globalized food systems to ensure good public outcomes;
- Mobilizing public and private sector investments and providing market-based incentives to advance equitable and sustainable development goals;
- Establishing equitable regional and global trade arrangements to support developing countries' food and livelihood security goals, and revising ownership laws to ensure poor and/or vulnerable communities' equitable use, access to and control over land, water, seeds and germplasm; and
- Establishing new, transparent, democratically governed institutional arrangements to accomplish these goals.

Source: IAASTD, 2009a and b (see also Ishii-Eiteman, 2009; and Hoffmann, 2011).

unprecedented levels of corporate control of the region's food and agricultural system (Hendrickson et al., 2009). As these corporations have extended their operations into Latin America, Asia and Eastern Europe, their global influence has expanded, with adverse consequences for small-scale farmers around the world (McIntyre et al., 2009a; 2009b). The result has been a dramatic reduction in competition and fair access to markets for small and medium-scale producers, labour, independent retailers and consumers. As consolidation has increased, a handful of transnational agribusinesses have gained growing influence over the production and distribution of food, both domestically and internationally (Hendrickson et al., 2009; Hubbard, 2009; De Schutter, 2010c; see also figure 12 below). This in turn has enabled them to exert significant political influence over public policy and research.

3. Corporate influence over public policy

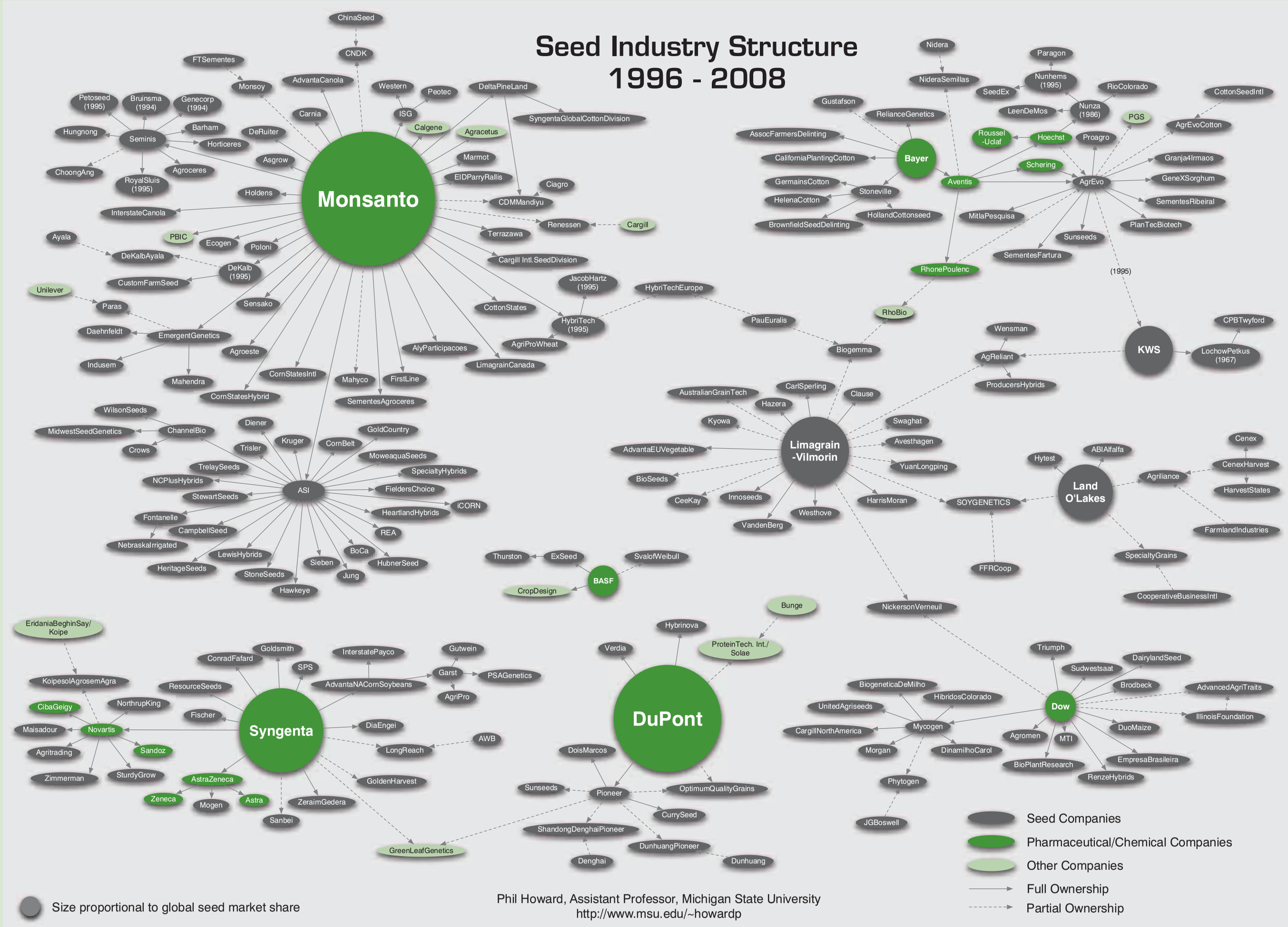
Agribusinesses spend billions of dollars lobbying

Box 6: Corporate influence over public policy

Transnational corporations exercise significant influence over the formation of national and international public policy. Below are some illustrative examples.

- Soon after forest fires in the Russian Federation devastated its wheat crops in 2010, the multinational grain trader, Glencore, speculating on a profitable spike in wheat prices, urged the Russian Federation to ban wheat exports, thereby provoking the desired price surge that had global repercussions (Patel, 2011).
- In Brazil, a 2010 Congressional bill, co-authored by a lawyer for the Council for Biotechnology Information, linked to Monsanto, BASF, Bayer, Cargill, Dupont and others, proposed repeal of a Biosafety Law prohibition on "genetic use restriction technologies" also known as "terminator technologies" (Camargo, 2010).
- Monsanto and its affiliates lobbied Indonesian legislators in the 1990s to support genetically engineered (GE) crops. In 2005, the firm was fined $1.5 million by the United States Department of Justice for violating the Foreign Corrupt Practices Act by bribing a senior Indonesian Environment Ministry official (Birchall, 2005).
- Chemical companies commonly sit on panels and committees that advise regulators. For example, a representative from Dow Chemical is serving on the Endocrine Disruptor Screening and Testing Advisory Committee of the United States Environmental Protection Agency.
- In 2002, Malaysia banned the highly toxic chemical herbicide, Paraquat. Its manufacturer, Syngenta, joined Malaysia's influential palm oil industry in pressuring the Government to reverse the ban, which it did in 2006. Malaysia's Pesticide Board subsequently ruled that Paraquat use could continue pending results from a study on alternatives. The study has not been released and Paraquat continues to be used (Watts, 2010).

Figure 12: Structure of the global seed industry over the period 1996–2008



Source: Reproduced with the kind permission of Howard, 2009, from: http://www.msu.edu/~howardp/seedindustry.html.

Note: Consolidation has increased in the international seed industry in recent decades. The chart depicts relationships between major seed companies and their subsidiaries in 2008, after 12 years of consolidation. The largest firms are represented as circles, with the size proportional to their share in the global commercial seed market.

Box 7: Revolving door

Corporate executives from major agribusinesses appointed to public agencies have frequently participated in the drafting of regulatory rules that are favourable to their industry's interests.[a] Below are some examples from various reports.

- A Brazilian attorney represented Monsanto and its Brazilian subsidiary, Monsoy, in various court cases between 1998 and 2002. Moving to government service in 2005, he coordinated the high-level inter-ministerial working group that established the decree to implement Brazil's pro-GE Biosafety Law. The law –applauded by Monsanto[b]– established a National Biosafety Council on which the former Monsanto attorney served as executive secretary from 2005 to 2010.
- A Syngenta lobbyist that represented the biotech company at an EU hearing in 2008 had previously worked for the European Union Food Safety Authority (EFSA) where she had developed GE guidance documents. Her move violated the EFSA's required two-year waiting period. The lobbyist is currently Syngenta's Head of Biotech Regulatory Affairs for Europe, Africa and the Middle East (Testbiotech, 2009 and 2010; SP International, 2010).
- A lawyer for Monsanto moved to the United States Food and Drug Administration (FDA) and the United States Department of Agriculture (USDA) in the 1990s, during which time he approved Monsanto's controversial GE bovine growth hormone and developed pro-agricultural biotechnology policies based on the concept of "substantial equivalence." He returned to Monsanto as vice president for public policy in 1998, before rejoining the FDA in 2010 (Nestle, 2002; USFDA, 2010).
- A former corporate counsel for the pesticide and biotechnology company, DuPont, was appointed in January 2011 to serve as general counsel for the USDA. Soon after, the USDA proposed a dramatic reduction in agency responsibility for regulating GE crops. A two-year pilot program launched in April 2011 now allows biotechnology firms to conduct environmental reviews of their own GE products as part of the United States' regulatory process.[c] In November 2011, USDA announced additional plans to streamline its GE regulatory approval process in order to "reduce the length of the petition process." [d]

Note: a See also Center for Responsive Politics, 2011, Agribusiness lobbying, at: www.opensecrets.org/lobby/indus.php?id=A&year=2010, and Revolving door, at: www.opensecrets.org/revolving/index.php.

b See Monsanto, Monsanto encouraged by enactment of Brazilian biosafety law. News release, 24 March 2005, at: http://monsanto.mediaroom.com/index.php?s=43&item=62.

c USDA (2011). Solicitation of Letters of Interest to Participate in National Environmental Policy Act Pilot Project. Animal and Plant Health Inspection Service [Docket No. APHIS–2010–0117], Federal Register, Vol. 76, No. 67, Thursday, April 7, 2011/Notices: 19309–19310. Washington, DC. USDA's pilot programme is described at: www.aphis.usda.gov/biotechnology/nepa_pilot.shtml.

d USDA's November 2011 plans to speed up the GE approval process are described at: www.aphis.usda.gov/newsroom/2011/11/ge_petition_process.shtml. The collaboration between Monsanto and USDA in preparation of environmental reviews of Monsanto's GE products is analysed at: www.truth-out.org/under-industry-pressure-usda-works-speed-approval-monsantos-genetically-engineered-crops/1323453319. Government documents obtained under a Freedom of Information Act request are available at: www.truth-out.org/why-monsanto-always-wins67976.

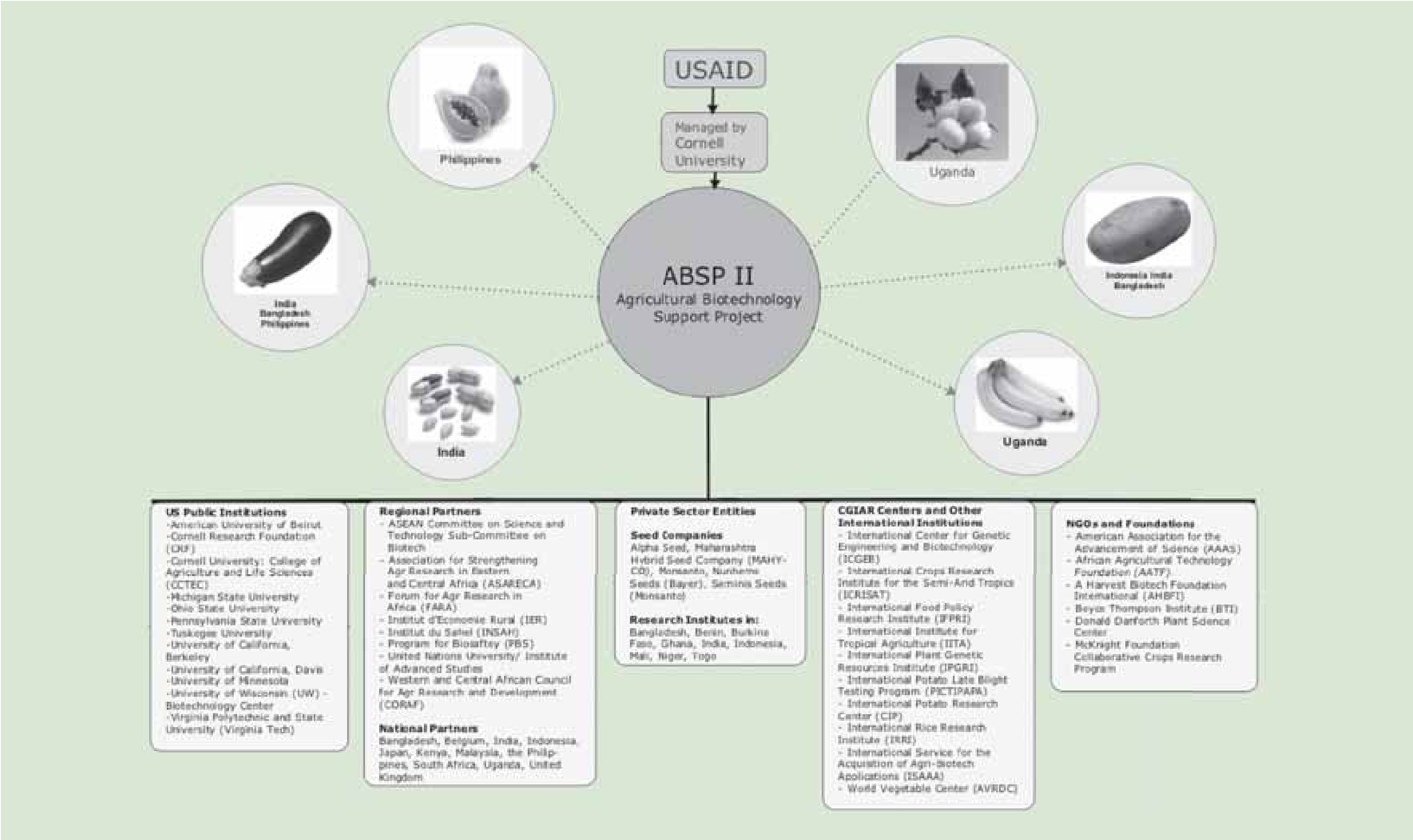
public agencies and officials, in both national and international policy-making arenas, and have, in many instances, influenced policy decisions to their benefit (boxes 6 and 7). This influence weakens government commitment to more strictly regulate commercial actors, remove perverse incentives that favour corporate profit over public interest, revise ownership laws and restore public access to and control over productive resources that have been privatized.

4. Legal impediments to sustainable agricultural research and practice

Security of tenure and access to land are vital to enable farmers to invest in longer term resource-conserving strategies and meet livelihood and food security goals at household and national levels. The lack of national laws to secure small-scale farmers' tenure and access to productive resources (e.g. seeds, germplasm, land, water) undermines efforts to promote a conversion to sustainable practices. Instead, intellectual property (IP) laws have privatized those resources, transferring ownership to commercial interests (IAASTD, 2009a).

IP laws are also driving agricultural research in support of private sector goals, associated with product development rather than ecological resilience or poverty reduction. The Bayh-Dole Act of 1980, for

Figure 13: USAID-funded Agricultural Biotechnology Support Project (ABSP-Phase II): target countries, GE crops in development and project partners



Source: Pesticide Action Network North America (2010). Graphic developed by A. Munimus from project information provided at: http://www.absp2.cornell.edu/.

example, radically altered the political and economic landscape of public sector research in the United States, mandating patents on research outcomes. When universities assign exclusive licensing rights to corporations, core research benefits are removed from the public domain.

Scientists in developing countries are encouraged by incentives and technical support from university patent offices to undertake research that is likely to earn royalty revenues for the university, as observed in Uganda (Louwaars et al., 2005). Increasingly, universities are redirecting their research to meet the short-term financial goals of sponsoring corporations rather than broader public interest goals, as reflected in the emergence of a "university-industrial complex" (Press and Washburn, 2000; Washburn, 2005).

Scientists' ability to conduct independent assessments of patented GE seeds is also impeded by IP rules that require them to first secure approval for their research plan from the patent-holder (Hubbard, 2009). Indeed, in 2009, in a letter to the United States Environmental Protection Agency, over two dozen university scientists complained of the stifling effects of IP laws on independent research and innovation (Pollack, 2009).

Corporate ownership of both productive resources and IP has constrained agricultural transformation in other ways as well (Brennan et al., 2005; Pray, Oehmke and Naseem, 2005). These ownership rules have contributed to the erosion of genetic diversity, local knowledge, social equity and food sovereignty (Dreyfus et al., 2009).

Finally, the lack of adequate anti-trust and competition laws at national and international levels, and weak judicial systems that are unable to properly enforce existing laws have supported the unprecedented pace of corporate consolidation and adverse effects on family farming over the past two decades (De Schutter, 2009b; Hendrickson et al., 2009).

5. Institutional biases

Bias within institutional arrangements – shaped by pre-analytic assumptions, professional inertia and "path dependency," and upheld by geopolitical concerns and the influence of vested interests – can strongly privilege one development model over others (Dreyfus et al., 2009). In the case of agriculture, politically and economically dominant actors, such as the World Bank, international research centres, and developed-country aid and trade agencies, all played a formative role in establishing the "Green Revolution" model as one to be replicated and emulated, at the expense of alternative models that emphasized more holistic, ecological and farmer-led approaches (Brooks et al., 2009; Dreyfus et al., 2009; Cullather, 2010; Brooks, 2010 and 2011).

The persistence of these biases today is reflected in the number of strategic initiatives of major international donors that seek to promote high-external-input, commercial or industrial agriculture, even among small-scale farmers, despite evidence that reveals the damaging effects of this approach and the need to strengthen site-specific ecological approaches that provide multi-functional benefits. For example, emphasis on increasing productivity through the research, development and export of new products and biotechnologies underpins the United States Feed the Future Initiative,[42] the Agricultural Biotechnology Support Program of the United States Agency for International Development, [43] the agriculture programme of the world's largest private foundation (Bill and Melinda Gates Foundation, 2010) and the Consultative Group on International Agricultural Research (Edwards, 2008; Brooks, 2010 and 2011; Feed the Future, 2010; Tuckey, 2010). Many of these development initiatives are closely interwoven and share the same corporate partners (figure 13). In such cases, bilateral and multilateral development aid provides an effective vehicle for market entry.

6. Global trade: driver or constraint?

Global trade has significant potential to support robust national and regional economies and drive a transition towards ecological agriculture. However, trade liberalization that has opened developing-country markets to international competition too quickly or too extensively has undermined the rural sector and degraded the environment (IAASTD, 2009a and b). As a result, developing countries have been left with diminished capacity for food production, making them more vulnerable to international food price and supply volatility, and reducing their food and livelihood security (Khor, 2008).

A fundamental reform of global trade rules towards fair and ecological agriculture has been proposed and described by a number of experts (e.g. Izac et al., 2009; also see Khor and Lim in chapter 5 of this Review). Yet progress towards establishing a new and fair trade regime remains constrained by the influence of a few powerful countries and commercial interests operating in global policy arenas such as the World Trade Organization (WTO). Anti-democratic processes and asymmetrical power relationships within the WTO prevent civil society and governments of developing countries from securing reform of the global trade regime recommended by, for example, the IAASTD and UNCTAD (Khor, 2008 and 2009; South Centre, 2011).

B. Curtailing concentration of power and excess of influence in the globalized system

The democratizing of institutions that shape global food and agriculture requires both courage and sustained engagement by visionary political leaders, researchers, private sector actors and all sectors of civil society. The participation of all stakeholders, particularly historically marginalized rural communities in developing countries, as equal partners – and not simply as stepping stones in a "consultative" process – is an essential ingredient for revitalizing local and regional food systems, driving innovation that meets global food and livelihood needs, and building robust local economies.

A progressive approach to overcoming the institutional and market-power constraints identified above should include commitment to:

- Undertake a full cost analysis of national and global food and agricultural systems;
- Provide institutional support for small-scale farmers, and women's and workers' organizations that strengthens their negotiating power in markets dominated by transnational buyers;
- Strengthen and broaden the scope of national and international competition policies to reverse trends in farm and agribusiness concentration, end unfair business practices across the global food production and supply chain, and curtail dominant buyer power which threatens small-scale farmers' food and livelihood security (see De Schutter, 2010c);
- Establish and enforce strong codes of conduct to govern private-public partnerships and public policy-making processes in order to minimize potential conflicts of interest which unfairly or inappropriately benefit private sector actors;
- Establish an international review mechanism to investigate agrifood sector concentration, anti-competitive practices and impacts across national borders, develop standards of corporate behaviour and recommend policy options;
- Revise IP and other ownership rules and incentives in order to reorient public policy and research towards equitable and sustainable development goals;
- Establish means of preventing conflict of interest in partnerships, investments and policy-making processes;
- Build developing countries' capacities for trade analysis and negotiation leading to more equitable trade rules. Strategic impact assessments could provide useful empirical evidence of the social, environmental and economic trade-offs of various trade instruments;
- Restrain financial speculation over food commodities that distorts markets and price signals; and
- Establish and strengthen democratic decision-making processes and increase civil society participation in policy-making processes. The success of the Tamil Nadu Women's Collective in transforming regional food and agricultural systems by supporting rural women as co-decision-makers in the community and in political office is instructive in this respect (IATP, 2010).

Commentary XII: Agriculture, Food and Energy

Gunnar Rundgren
Grolink AB Consultancy, Sweden

Abstract

In a world with a rapidly increasing human population and the simultaneous depletion of natural resources, the industrial logic of replacing human labour with oil and other natural resources makes less and less sense. Increasing energy prices will reverse some of the developments that were made possible by cheap fossil fuel. This poses a challenge for society, but also an opportunity to steer towards a path of true sustainability, including the adoption of more sustainable agricultural methods (such as organic farming) and more localized food production networks. That those changes will also serve to mitigate climate change is another strong argument in favour of such a shift.

A. Introduction

A combination of cheap fossil fuel and market orientation led to the industrialization of farming. While labour productivity in agriculture has skyrocketed, energy productivity has plummeted. The winners have been agribusinesses and the losers have been small farms, especially in developing countries. With increasing shortages of fossil-fuel-based energy and natural resources and the rapid growth of the world's population, we need to fundamentally transform agriculture into a net energy producer, as it was throughout history. The simple equation has always been that it is necessary to get substantially more energy out of the food than is put into its production. As long as energy input is human labour it is an iron law that can only be skipped for shorter periods. Agricultural workers should not only be able to feed themselves, but also other family members who are too young, too old or too sick to work, as well as a few others that supply services. Finally, in almost all societies there have been rulers who have appropriated a large proportion of the production.

B. 250 billion energy slaves

To have an idea of how important the deployment of external energy sources has been for our modern societies, one can contrast the energy embedded in human labour with the external energy sources that are exploited. A rough calculation shows that the 7.71 tons of oil equivalents (toes)[44] of energy used annually by the average American (compared with 0.25 toes used by the average Senegalese), corresponds to the food consumption of 400 people. That represent the "energy slaves" (in the form of fossil fuel) working for him or her. Another way of looking at it, from an economic perspective, is that a barrel of oil represents the energy of 25,000 hours of human toil (i.e. 14 persons working for a year under normal labour standards). Even with an oil price of several hundred dollars per barrel, this is very cheap compared with human labour (Rundgren, 2012).

According to the FAO (2000), 6,000 megajoules (MJ) of fossil energy (corresponding to one barrel of oil) is used to produce one ton of maize in industrial farming, while for the production of maize using traditional methods in Mexico, for example, only 180 MJ (corresponding to 4.8 litres of oil) is used. This calculation includes energy for synthetic fertilizers, irrigation and machinery, but not the energy used for making machinery, transporting products to and from the farm, and for construction of farm buildings. In modern rice farming, the energy return on energy invested (EROI) is less than 1 (i.e. there is more energy consumed than produced) and in modern maize farming it is slightly more than 1, while traditional production of rice and maize gives a return of 60 to 70 times on energy used (FAO, 2000).

The total energy harvested *per hectare* can increase substantially with increased use of ancillary energy, which can take the form of better (and timelier) soil preparation, irrigation[45] and the application of (chemical) fertilizers that are very energy demanding, to name a few. The ratio between energy return and energy input (i.e. efficiency in use of energy) seems to be fairly constant up to a certain level, after which it deteriorates rapidly. Industrial farming systems have long passed this level. Harvested energy *per labour unit* increases dramatically with increased input of energy by a factor of between 10 and 100, allowing the most advanced agricultural systems to have one farmer for more than 100 persons (Bayliss-Smith, 1982).

C. Why oil and grain prices move in tandem

Farming uses energy in many different forms: diesel for tractors and pumps, and electricity for pumps, fans and indoor machinery such as milking machines. Fertilizers account for a large proportion of energy use. Energy represents 90 per cent of the production costs of nitrogen fertilizers, 30 per cent of those of phosphorus fertilizers and 15 per cent of those of potassium fertilizers. According to the United States Congressional Research Services (US CRS, 2004), energy costs in the United States represent between 22 per cent and 27 per cent of the production costs of wheat, maize and cotton and 14 per cent of those of soybeans.[46] These figures do not include embedded energy costs in items such as buildings and machinery, which means that the actual share of energy costs is substantially higher. In Argentina, energy costs were calculated as accounting for 43 per cent of the production costs of grain in 2006 (Baltzer, Hansen and Lind, 2008). When energy prices rise, agricultural commodity prices follow suit, as was seen in the food and oil price hikes in 2007–2008.[47] Higher energy prices influence food prices in four different ways:

i) By making food production more expensive;
ii) By making the production of crops for biofuel more remunerative and therefore reducing the production of food, thereby leading to higher food prices;
iii) Increasing transportation costs, which have a direct impact on food prices;
iv) Reducing competition in the food sector (i.e. increased transportation costs alleviate the pressure of global competition) (Rundgren, 2012).

D. It takes more energy to eat than to farm

The increase of energy use in agriculture was particularly rapid during the period between the Second World War and the first oil price shock in 1973. For example, in the United Kingdom, while the agricultural labour force was reduced to half between 1952 and 1972, energy use tripled (Bayliss-Smith, 1982). In the United States, energy use fell from the mid-1970s to the mid-1980s as a response to higher oil prices, but it stabilized thereafter (Hendrickson, 1994). However, looking at the entire food chain, energy use has constantly increased. Use of energy along the food chain for food purchases by or for households in the United States increased between 1997 and 2002 at more than six times the rate of increase in total domestic energy use. As a share of the national energy budget, food-related energy use grew from 12.2 per cent in 1997 to 14.4 per cent in 2002 (US CRS, 2004) (see also the comment of GRAIN in this chapter). In pre-industrial and semi-industrial agricultural systems, most of the food is sold, eaten and prepared close to where it is produced, but modern food chains are highly centralized and globalized. In industrialized countries, between 10 and 15 times more energy is used in the food system than is contained in the food we eat (Hendrickson, 1994).

A large proportion of the energy in the food system is used by consumers for buying, storing and preparing food. For example, in Sweden in 1997, of the total energy use in the food chain, agricultural production accounted for 15–19 per cent, processing for 17–20 per cent, distribution and retail for 20–29 per cent and consumption for 38–45 per cent. Another 7–11 per cent of the total energy is consumed by much-discussed transport, particularly in the final stretch to the point of purchase by the consumer. For instance, a person driving a car a distance of five kilometres for shopping uses a lot more energy per food unit than a ship transporting meat or soy from another continent. Also, in some developing countries, consumption takes the lion's share of energy use for food, in this case, mainly from cooking over an open fire. The energy used by this traditional method of cooking is equivalent to about 1,500 kWh per capita (corresponding to slightly more than a cubic metre of firewood), which is somewhere between half and one third of what is used per capita for cooking in Sweden or the United States (Uhlin, 1997). Cooking represents more than a fifth of the total energy consumption in Africa and Asia,[48] and in some countries, it represents up to or over 90 per cent of household energy consumption (IEA, 2006). Cooking consumes more energy than the food contains. Thus, while farming in developing countries and traditional systems is energy efficient, cooking is not.

Table 1: Agricultural labour productivity ($ per person/year)

	1990–1992	2001–2003	Agriculture as a share of GDP (%)
Low-income countries	315	363	20
Middle-income countries	530	708	9
High-income countries	14,997	24,438	2
France	22,234	39,220	2
United Kingdom	22,506	25,876	1
United States	20,797	36,216	1
Brazil	1,507	2,790	5
India	332	381	4
China	254	368	12
Malawi	72	130	36

Source: World Bank, 2008.

In a world with a rapidly increasing human population and the simultaneous depletion of natural resources, the industrial logic of replacing human labour with oil and other natural resources makes less and less sense. Increasing energy prices will reverse some of the developments that were made possible by cheap fossil fuel. This poses a challenge for society, but also an opportunity to steer towards a path of true sustainability, including the adoption of more sustainable agricultural methods (such as organic farming) and more localized food production networks. That those changes will also serve to mitigate climate change is another strong argument in favour of such a shift (in this regard, also see the lead article of chapter 1 and the comment of Leu).

The desired objective should not be to abolish the use of external energy and rely solely on manual labour; rather, it should be about finding a new balance that works on a global scale and is sustainable. Renewable energy, such as bio-energy, windmills and water mills have been used in farming for thousands of years. These could be improved and more widely adopted, and solar energy and biogas could also be added to the mix. It is not likely that renewable energy will allow such wasteful systems as exist today. For example, very cheap energy makes it profitable to use that energy to bind atmospheric nitrogen instead of using natural nitrogen fixation.

E. Unequal energy access and unequal terms of trade

Commercialization is promoted as the recipe for development for the almost half a billion smallholder farmers in the world. Their traditional modes of farming are built on a rather high degree of autonomy, and these regenerate most of the needed resources, such as labour, capital, soil fertility and pest control, within the farming system. By nature, peasants resist commercialization because they wish to minimize risk and dependence (Van der Ploeg, 2009). If they were to be coerced into commercializing their production, most of them would simply not survive in the struggle for "modernization", and if they survived, there would be enormous overproduction. European farms experienced difficulties coping with competition from North America, especially after the introduction of steamship transport. The response was to introduce protectionist measures, even though they faced much less competitive pressure than today's poor farmers in developing countries. In addition, because of productivity gains in developed countries, global agricultural commodity prices fell by about 60 per cent during the period 1960–2000 (Dorward et al., 2002). Over the past few decades, as productivity and energy use by the poorest farmers have remained much the same, the productivity gap has widened, both relatively and in absolute numbers (table 1). As a result, it is clear that smallholder farmers in developing countries have been losing out. At current prices, it would require one lifetime of labour[49] by a farmer on a non-mechanized farm to acquire a pair of oxen and small animal-drawn equipment, and ten generations of labour to buy a small tractor (Mazoyer and Roudart, 2006).

It is entirely unrealistic to believe that smallholder farmers in developing countries, with their limited resources, would be able to compete in world markets for staple foods, where energy access is the main factor of competitive advantage. In reality, an increasing number of developing countries are becoming net food importers. Cheap energy may have been considered a way out of this situation, but this has not been the case. Indeed, it is cheap energy that has kept down the prices of agricultural products, and thereby the market value of smallholder farmers' labour to a dollar per day. And it is cheap energy that has allowed income gaps to widen to unprecedented levels because the rich producers have always been able to use more cheap energy than the poor. Thus the gap between those relying on their own labour and those relying on the use of fossil fuel has increased.

Energy scarcity and rising energy prices will result in less global competition and higher food prices. Such a development, while painful for many societies and for net food importers in the short run, will, nevertheless, be better for the smallholder farmers in developing countries in the long run, because it will encourage energy-efficient, low-external-input-dependent, closed loop, regenerative forms of agriculture with a greater focus on regional markets. Policymakers should seize this opportunity to promote a paradigm shift towards this form of agriculture, instead of promoting continued or increased dependence of agriculture on external inputs (e.g. fertilizers, genetically modified organisms and credits) and continued global competition in a market where the big players have unlimited access to cheap energy.

Commentary XIII: Sustainable Agriculture and Off-Grid Renewable Energy

Mae-Wan Ho
Institute of Science in Society, London

Abstract

Small integrated farms with off-grid renewable energy may be the perfect solution to the food and financial crises while mitigating and adapting to climate change.

A. Food crisis, global economic instability and political unrest

Soaring food prices were a major trigger for the riots that destabilized North Africa and West Asia, and have since spread to many other African countries (Harvey, 2011; Ho, 2011d). The FAO Food Price Index hit an all-time high in February 2011,[50] and reached 211 points in November 2011, some 30 points lower than at its peak, but 10 points higher than the average for 2008. This has been happening as the global economy is still staggering from the 2008 financial (and food) crisis, with public debt expanding and unemployment sky high (Filger, 2011).

Lester Brown (2011), veteran world-watcher, notes that food has quickly become the hidden driver of world politics, and food crises are going to become increasingly common. He says, "Scarcity is the new norm." The world is facing growing demand for food as population increases, yet food crops and land are being diverted to produce biofuels. In 2010, the United States alone turned 126 million tons of its 400 million tons of corn harvest into ethanol. At the same time, the world's ability to produce food is diminishing. Aquifers are running dry in the major food-producing countries where half of the world's population lives. There is widespread soil erosion and desertification, and global warming and weather extremes are already reducing crop yields (Peng et al., 2004; Lobell, Schlenker and Cost-Roberts, 2011; Jones, 2011; *Science Daily*, 2011), hitting the most vulnerable people in sub-Saharan Africa and South Asia the hardest.

Brown (2011) warns, "We are now so close to the edge that a breakdown in the food system could come at any time." He adds: "At issue now is whether the world can go beyond focusing on the symptoms of the deteriorating food situation and instead attack the underlying causes. If we cannot produce higher crop yields with less water and conserve fertile soils, many agricultural areas will cease to be viable… If we cannot move at wartime speed to stabilize the climate, we may not be able to avoid runaway food prices… The time to act is now – before the food crisis of 2011 becomes the new normal."

B. The importance of small family farms

There is an emerging scientific consensus that a shift to small-scale sustainable agriculture and localized food systems will address most, if not all, of the underlying causes of deteriorating agricultural productivity as well as the conservation of natural soil and water resources while saving the climate (Ho et al., 2008; IAASTD (undated); Hoffmann, 2011; De Schutter, 2011).

Small family farming is the dominant form of agriculture in the world, especially in the developing countries of Africa and Asia. Approximately 3 billion people live in rural areas in developing countries, which also include 80 per cent of the poor. Around 2.5 billion people are involved in agriculture as farmers or workers, and at least 75 per cent of farms in the majority of Asian and African countries are 2 ha or smaller (Quan, 2011). As Hoffmann (2011) points out, Millennium Development Goal (MDG) 1 aims at eradicating extreme hunger and poverty, and one of the most effective ways of halving both the number of hungry and poor by 2015 is to make the transition towards more sustainable forms of agriculture "that nourish the land and people and provide an opportunity for decent, financially rewarding and gender equal jobs." At the same time, this would *help* meet the health targets of MDGs 3 and 6 in providing a more diverse, safe, nutritious and affordable diet (see also Ho et al., 2008).

Small farms generally produce more per hectare than large ones, so much so that economists have long observed and debated this apparently paradoxical inverse relationship between farm size and productivity (Quan, 2011). Small farms are 2 to 10 times as productive and much more profitable, and not just in developing countries (Rosset, 2006). The United States Agricultural Census of 1992 found a sharp decline in net income, from $1,400/acre to $12/acre as farm size increased from 4 acres to 6,709 acres (Rosset, 1999). Small farms are also associated with "intensive use of household and community labour, high levels of motivation and much lower supervision and transaction costs" (Quan, 2011), which may well explain their economic advantages, but not their actual productivity. These farms are highly productive because they are typically biodiverse systems that integrate multiple crops and livestock, which enables them to maximize synergetic relationships while minimizing wastes, as they turn wastes such as farmyard manure into fertilizer. In effect, they embody the circular economy of nature (Ho et al., 2008) wherein energy and nutrients are recycled within the ecosystem for maximum productivity and carbon sequestration, both above and below ground (see, for example, Ho, 2008 for a detailed description of this "thermodynamics of organisms and sustainable systems").

C. The importance of renewable energy

To substantially improve living standards, sustainable farming is not enough; access to modern energy is also crucial. Indeed, lack of access to modern energy is generally recognized as the biggest obstacle to sustainable development. According to the International Energy Agency (IEA, 2010), "Lack of access to modern energy services is a serious hindrance to economic and social development and must be overcome if the UN Millennium Development Goals (MDGs) are to be achieved." This view is echoed by the Academy of Science of South Africa (2010), which states: "Access to modern energy services, defined as electricity and clean cooking fuels, is central to a country's development."

Worldwide, 1.4 billion people lack access to electricity, 85 per cent of whom live in rural areas, and 2.7 billion people still rely on traditional biomass fuels for cooking and heating (IEA, 2010). The greatest challenge is in sub-Saharan Africa, where only 31 per cent of the population has access to electricity, the lowest level in the world, and if South Africa is excluded, only 28 per cent have such access.

There is a close correlation between income levels and access to modern energy. Countries with a large proportion of the population living on an income of less than $2 per day tend to have low electrification rates and a high percentage of the population that relies on traditional biomass. The World Health Organization (WHO, 2011) estimates that 1.45 million people die prematurely each year from household air pollution due to inefficient biomass combustion, a significant proportion being young children. This is greater than premature deaths from malaria or tuberculosis.

Small agroecological farms are ideally served by new renewable energies that can be generated and used on-site and in off-grid situations most often found in developing countries (Ho et al., 2009; Ho, 2010a). The renewable energies generated can also serve local businesses, stimulate local economies and create numerous employment opportunities.

D. Off-grid renewable power systems are entering the mainstream worldwide

Within the past few years, off-grid power systems have entered the mainstream, driven by the ready availability of renewable energy options that can cost less than grid connections.

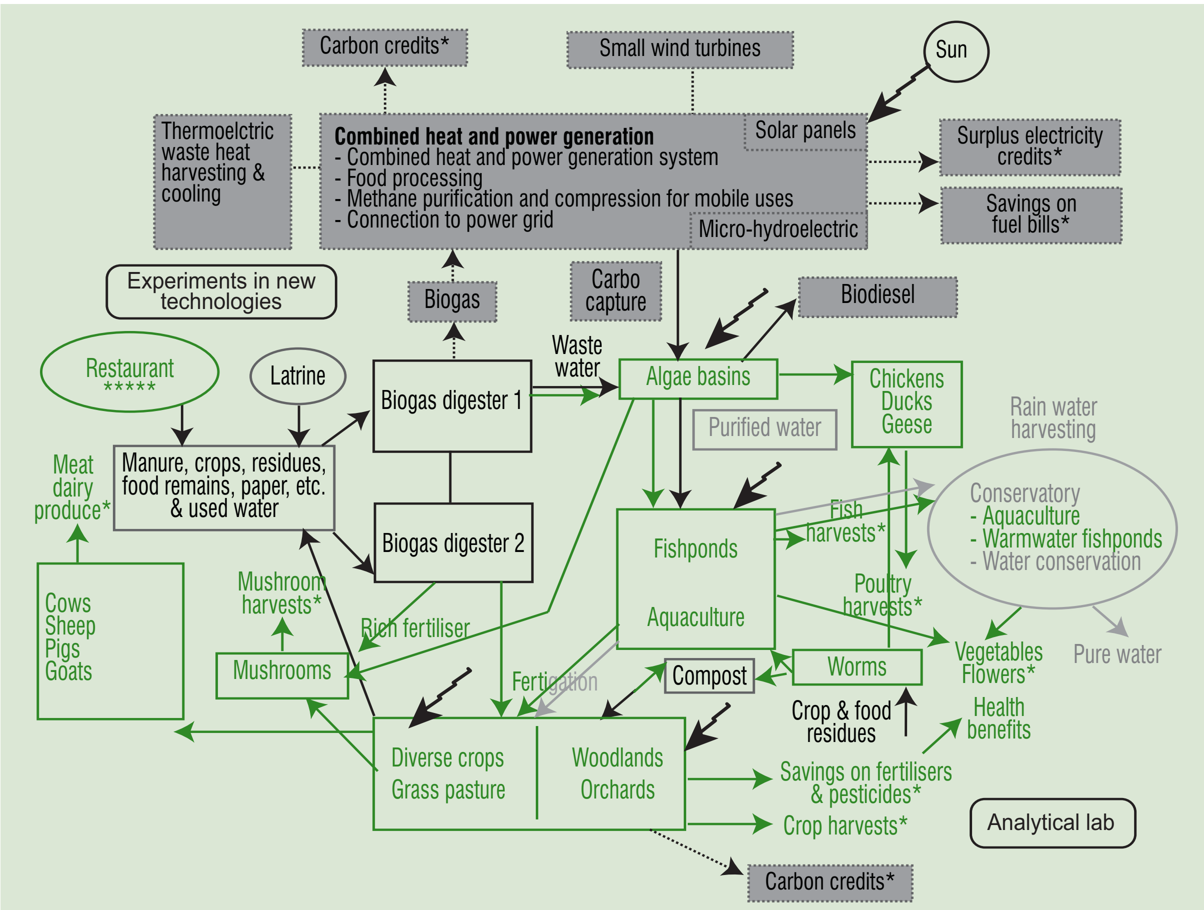
A United Kingdom company, Energy Solutions, advertises on its website[51] that homes in Europe, including the United Kingdom, "are looking at the potential benefits of supplying some, if not all their domestic power requirement from off-grid sources." This could be for a variety of reasons, such as connection to the grid being too expensive, and the desire to reduce energy bills, protection from power cuts and reduction of GHG emissions. Solar panels, wind turbines and small generators are suitable for most homes, and a system with a battery connected to a battery charger/inverter is the most convenient.

Examples of small-scale off-grid energy provision based on renewables can be found across Scotland (Community Energy Scotland, 2011), such as in remote ferry waiting rooms on the Western Iles and the Charles Inglis Clark Memorial hut on Ben Nevis that uses small wind turbines. Photovoltaic (PV) installations integrated with batteries are often used where only a small amount of power is required, as for lighting, maintaining power for monitoring equipment or maintaining water treatment facilities. However, it is in developing countries, that off-grid renewable energy is rapidly gaining ground. In these countries, power requirements are generally low and electronic lighting and telecommunication equipment are improving rapidly, with low power requirements and reliable performance, and requiring little or no maintenance (Ho, 2010a). Three examples of large-scale off-grid renewable energy use with varying degrees of success are the Grameen Shakti in Bangladesh (Ho, 2011a), Lighting Africa (Ho, 2011b) and Biogas for China's Socialist Countryside (Ho, 2011c).

Grameen Shakti is a non-profit organization founded in 1996 to promote, develop and supply renewable energy to the rural poor of Bangladesh. It started by training "barefoot women engineers" for installing, maintaining and repairing solar panels, lights, telephone charging, batteries and other accessories. It has now become one of the world's largest and fastest growing renewable energy organizations through a system of microfinancing, training of technicians (mainly women) for installation, maintenance and repair and provision of services, including buy-back. It runs technology centres for training throughout the country (see Ho, 2011a for details). At the end of May 2011, Grameen Shakti had installed 636,322 solar home systems, 18,046 biogas plants and 304,414 improved cooking stoves. It had also trained a total of 28,932 technicians in 46 technology centres nationwide, covering all the districts. Its beneficiaries are 40,000 villages with a total of about 4 million people (Grameen Shakti, 2011). What began as a grassroots endeavour to provide solar light for the rural population has now attracted the backing of the World Bank.

Lighting Africa is now a joint World Bank and International Finance Corporation programme that aims to help develop commercial off-grid lighting

Figure 14: Dream Farm 2: an integrated food and energy system



Source: Ho et al., 2008.

Table 2: Green potential of organic agriculture and anaerobic digestion in China

	CO_2e savings (Mt)	(% national)	Energy savings (EJ)	(% national)
Organic agriculture				
N fertilizers saving	179.5	2.38	2.608	3.61
N_2O prevented	92.7	1.23		
Carbon sequestration	682.9	9.07		
Total for organic agriculture	**955.1**	**12.69**	**2.608**	**3.61**
Anaerobic digestion				
Livestock manure GHG saving	70.3	0.09		
Methane produced	215.5	2.86	3.124	4.33
Humus manure methane	7.7	0.10	0.112	0.16
Straw methane	292.5	3.93	4.234	5.86
Total for anaerobic digestion	**586.0**	**7.79**	**7.470**	**10.35**
Total overall	**1,491.1**	**20.48**	**10.078**	**13.96**

Source: Ho, 2010b.

Note: Mt=megatons; EJ= Exajoule

Table 3: Green potential of Dream Farm 2

	CO_2e savings (Mt)	(% national)	Energy savings (EJ)	(% national)
Organic agriculture	955.1	-12.69	2.608	-3.61
Anaerobic digestion	586.0	-7.79	7.470	-10.35
Enery savings local gen.	1,287.1	-17.10	21.660	-30.00
Total	**2,828.2**	**-37.58**	**31.738**	**-43.96**

Source: Ho, 2010b.

markets in sub-Saharan Africa as part of the World Bank Group's wider efforts to improve access to energy.[52] It aims to provide safe, affordable, and modern off-grid lighting to 2.5 million people in Africa by 2012 and to 250 million by 2030. The market for off-grid lighting products is projected to grow at 40 to 50 per cent annually. In 2010 alone, sales of solar portable lanterns that had passed Lighting Africa's quality control tests grew by 70 per cent in Africa, resulting in more than 672,000 people having access to cleaner, safer, reliable lighting and improved energy (see Ho, 2011b for details).

In China, provision of biogas is an important part of the country's New Socialist Countryside programme launched in 2006 to improve the welfare of those living outside booming cities, which include the country's 130 million migrant workers and rural poor. China is one of the first countries in the world to use biogas technology, and it has been revived in successive campaigns by the present government to provide domestic sanitation and off-grid energy, and to modernize agriculture (for details, see Ho, 2011c; Li and Ho, 2006). An anaerobic digester producing biogas is typically combined with a greenhouse for growing vegetables and other crops, along with a pigsty so that pig and human manure can be digested, while CO_2 generated by the pigs boosts plant growth in the greenhouse. The biogas produced (typically 60 per cent of methane and 40 per cent of CO_2, along with traces of other gases) can be used as cooking fuel and to generate electricity, while the residue provides a rich fertilizer for crops. It is an example of the circular economy that has served Chinese peasants well in traditional Chinese agriculture (Ho, 2006). More elaborate models include orchards and solar panels. According to a recent survey from China's Ministry of Agriculture (Wang, 2011), 35 million household biogas tanks had been installed by the end of 2009 through 56,500 biogas projects. This exponential growth phase that started around 2001 is set to continue, along with medium and big digesters for community and industrial use. Anaerobic digestion of organic wastes is a key off-grid renewable energy technology for a truly green circular economy that could make a real difference for improving the lives of the rural poor.

E. Integrating sustainable farming and renewable energies in a circular economy

A model that explicitly integrates sustainable farming and renewable energies is Dream Farm 2, which optimizes the sustainable use of resources and minimizes waste in accordance with the circular economy principles (figure 14; see also Ho et al., 2008). It is patterned on a design developed by environmental engineer George Chan and the dyke-pond system of the Pearl River Delta that Chinese peasants have perfected over thousands of years – a system so productive that it supported 17 people per hectare in its heyday (Ho, 2006).

In the diagram, a grey background with dotted borders is for energy, green for agricultural produce, grey text for water conservation and flood control, and black is for waste in the ordinary sense of the word, which soon gets converted into food and energy resources. A rounded rectangle is for education and research into new science and technologies.

This ideal Dream Farm is complete with laboratory facilities for education, as well as a restaurant to take advantage of all the fresh produce. It is a perfect setting for developing cottage industries such as food preservation, processing, wine and cheese-making and bread-making, not to mention electronic workshops, battery charging, and retailing of renewable energy components and electronic devices. The synergies between agriculture and industries are obvious, especially in the case of food industries, as they are close to the source of production. Moreover, the organic wastes from these industries can go right back into anaerobic digestion to be converted into energy and nutrients for agriculture.

Some preliminary estimates, based on data and statistics made available by the Chinese Government and academics on the energy and carbon savings involved are presented in tables 2 and 3.

As can be seen from table 2, the combination of organic agriculture and anaerobic digestion has the potential to mitigate at least 20 per cent of national GHG emissions and save 14 per cent of energy consumption in China. If Dream Farm 2 were to be applied throughout the country, China would mitigate 38 per cent of its GHG emissions, and save 44 per cent of energy consumption, only counting anaerobic digestion, basically as a result of efficiency savings from using “waste” heat in combined heat and power generation, and avoiding loss from long distance transmission of electricity. A conservative allowance of 30 per cent efficiency saving (out of a maximum of about 60 per cent) gives the net carbon and energy savings shown in table 3. Again, this is from anaerobic digestion only. The savings could be far greater if low power consuming LED lighting and other electronic devices were to replace conventional high power consuming models.

With the addition of solar, wind or micro-hydroelectric, as appropriate, and batteries to store and maintain a steady power supply, such farms could compensate, in the best case scenario, for the carbon emissions and energy consumption of the entire country. Surplus energy from the farm could be used to supply homes and businesses in the vicinity through a mini-grid that could eventually link up to the national grid, if necessary or desirable. This could be a model for the natural evolution of connectivity and power-sharing. At the very least, such integrated food and energy farms would contribute to food security while playing their part, along with other sectors of the circular economy, in cutting their own carbon footprint. Furthermore, such small-scale agroecological farming and local renewable power generation are much more resistant and resilient to weather extremes, and indeed to earthquakes and sabotage.

Commentary XIV: Soil Erosion: A Threat to Food Security and Climate Change

David Pimentel and Michael Burgess
College of Agriculture and Life Sciences, Cornell University, Ithaca, New York

Abstract

Soil is the most valuable resource for world food production. Humans worldwide obtain more than 99.7 per cent of their food (calories) from land and less than 0.3 per cent from the oceans and other aquatic ecosystems. Each year about 10 million hectares (ha) (or about 0.7 per cent) of cropland are lost due to soil erosion, thus reducing the cropland available for world food production. This loss is a serious problem because, as the World Health Organization and the Food and Agriculture Organization of the United Nations report, at present 66 per cent of the world population (i.e. 4.7 billion people) is malnourished. Meanwhile, global warming is worsening and can be traced back to a not insignificant extent to increased soil erosion, fossil fuel use and the clearing of forests worldwide.

A. Introduction

The loss of soil from land surfaces by erosion is widespread and reduces the productivity of all natural ecosystems as well as that of agricultural, forest and pasture ecosystems (Lal and Stewart, 1990; Pimentel et al., 1995; Troeh, Hobbs and Donahue, 2004). Concurrently with the escalating human population, soil erosion, water availability, fossil energy use and climate change are emerging as the prime environmental problems throughout the world.

Currently, 66 per cent of the world population (i.e. 4.7 billion people) is malnourished (WHO, 2000; FAO, 2009b). This is the largest number of malnourished people ever in history. With the world population now at 7 billion, and expected to reach 9 billion by 2050, more food supplies will be needed. Considering that, at present, more than 99.7 per cent of human food (calories) comes from the land (FAO, 2011c), while less than 0.3 per cent derives from the oceans and other aquatic ecosystems, maintaining and augmenting the world's food supply basically depends on the productivity and quality of all soils.

Human-induced soil erosion and the associated deterioration in soil quality over many years have resulted in the loss of valuable soils and reduced productivity of the land, with some cropland being abandoned each year (Pimentel et al., 1995; Young, 1998; Pimentel, 2006). Clearly, when soil erosion diminishes soil quality it reduces the productivity of natural, agricultural and forest ecosystems. In addition, the important diversity of plants, animals and microbes is reduced.

In this paper, the diverse factors that cause soil erosion are assessed and the extent of damage associated with such erosion is analysed, with emphasis on the impact this may have on future human food security and climate change.

B. Causes of erosion

Erosion occurs when soil is left exposed to rain or wind energy. For example, about 1,000 mm of rain falling on one hectare (ha) of land in New York State provides the energy equivalent of 60,000 kcal per year. This is about the equivalent of the energy in 8 litres of gasoline. Raindrops hitting soil loosen it, and even if there is a gradient of only 1 per cent, it will cause the soil to flow downhill. This so-called, sheet erosion is the dominant type of erosion (Troeh, Hobbs and Donohue, 2004). The impact of soil erosion is intensified on all sloping land, where more than half of the surface soil is carried away as the water splashes downhill into valleys and streams.

Wind energy also has considerable power to dislodge surface soil particles and transport them over long distances. A dramatic example of this was the wind erosion in Kansas during the relatively dry and windy winter of 1995–1996. During just this one winter period, approximately 65 tons/ha of soil were eroded from this valuable cropland. Wind energy is sufficiently strong to propel soil particles thousands of kilometres, as illustrated by NASA's report of a cloud of soil being blown from the African continent to the South and North American continents.[53]

1. The role of vegetative cover

Land areas covered by plant biomass, living or dead, are more resistant and experience relatively little soil erosion, because raindrop and wind energy are dissipated by the biomass layer and the topsoil is held together by the biomass. For example, in Utah and Montana, it was found that as the amount of ground cover decreased from 100 per cent to less than 1 per cent, erosion rates increased approximately 200-fold (Trimbel and Mendel, 1995). In forested areas, a minimum of 60 per cent of forest cover is necessary to prevent serious soil erosion and landslides (United States Forest Conservation Act, 2002). Therefore, the extensive removal of forests for crops and pasture is followed by intensive soil erosion.

Loss of vegetation that provides soil cover is especially widespread in developing countries where populations are large and agricultural practices are often inadequate to protect topsoils. In addition, cooking and heating in these countries frequently depend on the use of crop residues for fuel (Pimentel and Pimentel, 2008). For example, about 60 per cent of crop residues in China and 90 per cent in Bangladesh are removed routinely from the land and burned as fuel (Wen, 1993). In areas where fuelwood and other biomass are scarce, even the roots of grasses and shrubs are collected and burned (Juo and Thurow, 1998). All these practices leave the soil barren and fully exposed to the forces of rain and wind erosion.

2. Other soil disturbances

While agriculture accounts for about 75 per cent of soil erosion worldwide, such erosion occurs whenever humans remove vegetative cover (Lal and Stewart, 1990). Construction of roads, parking lots and buildings is an example of this problem. However, although the rate of erosion from construction sites may be exceedingly high, it lasts for a relatively brief period, after which, once the land surface is seeded to grass or covered with other vegetation, the erosion declines (IECA, 1991).

Natural ecosystems also suffer losses from erosion. This is especially evident along stream banks, where erosion takes place naturally from the powerful action of adjacent moving water. Increased soil loss occurs on steep slopes (with gradients of 30 per cent or more) when a stream cuts through adjacent land, but even on relatively flat land, with only a 2 per cent gradient, stream banks are eroded during heavy rains and flooding.

C. Assessing soil erosion

It is estimated that approximately 75 billion tons of fertile soils worldwide are lost from agricultural systems each year (Myers, 1993), whereas relatively little erosion occurs in natural ecosystems. Soil scientists Lal and Stewart (1990) and Wen (1997) report that, annually, 6.6 billion tons of soil are lost in India and 5.5 billion tons in China. Considering these two countries together occupy only 13 per cent of the world's total land area, the estimated 75 billion tons of soil lost each year worldwide is conservative. The amount of soil lost annually in the United States is estimated to be about 3 billion tons (NAS, 2003).

1. Soil erosion on cropland worldwide

Currently, about 80 per cent of the world's agricultural land suffers moderate to severe erosion, while 10 per cent experiences slight erosion (Speth, 1994). Worldwide, erosion on cropland averages about 30 t/ha/yr, and ranges from 0.5 to 400 t/ha/yr (Pimentel et al., 1995). As a result of soil erosion over the past 40 years, about 30 per cent of the world's cropland has become unproductive, and much of that has been abandoned for crop use (Kendall and Pimentel, 1994; WRI, 1997).

Worldwide, the nearly 1.5 billion ha of land now under cultivation for crop production are almost equal in area to the amount of cropland (2 billion ha) that has been abandoned by humans since farming began. Such abandoned land, once biologically and economically productive, now produces little biomass, but also it has lost the considerable diversity of plants, animals and microbes it once supported (Heywood, 1995; Pimentel et al., 2006). Moreover, because of the decline in biomass in some agricultural production, less carbon is taken up and sequestered (see the commentary of GRAIN in this chapter).

Each year an estimated 10 million ha of cropland worldwide are abandoned due to their lack of productivity caused by soil erosion (Faeth and Crosson, 1994). Losses from soil erosion are highest in the agroecosystems of Asia, Africa and South

America, averaging 30 to 40 t/ha/yr (Pimentel, 2006). In developing countries, soil erosion is particularly severe on small farms that are often located on marginal lands where the soil quality is poor and the topography frequently steep. In addition, the poor farmers tend to raise row crops, such as corn and beans, which are highly susceptible to erosion because the crop vegetation does not cover the entire tilled soil surface (Stone and Moore, 1997). For example, in the Sierra region of Ecuador, about 60 per cent of the cropland has been abandoned because of the devastation caused by rainfall and wind erosion and inappropriate agricultural practices (Southgate and Whitaker, 1992). Similar problems are evident in the Amazonian region of South America, where vast forested areas have been cleared for cultivation of sugarcane and other crops, as well as for livestock production.

2. Erosion rates on pastures and rangelands

In the United States, in contrast to the average soil loss of 13 t/ha/yr from cropland, pastures lose soil at the rate of about 6 t/ha/yr (NAS, 2003). However, erosion rates on pastures intensify wherever overgrazing is allowed to occur. Even in the United States, about 75 per cent of non-Federal lands require conservation treatments to reduce grazing pressure (Johnson, 1995). More than half of all rangelands in the country – both non-Federal and Federal – are overgrazed and have become subject to high erosion rates (Bailey, 1996).

Although erosion rates on cropland in the United States have decreased during the past two decades, those on pastures and rangelands remain high (6 t/ha/yr) (NAS, 2003). Indeed, high erosion rates are typical on most of the world's pastures and rangelands (WRI, 1997). In many developing countries, heavy grazing by cattle, sheep and goats has removed most of the vegetative cover, exposing the soil to severe soil erosion. In Africa, about 80 per cent of the pasture and rangeland is seriously eroded and degraded (UN-NADAF, 1996). The prime causes of this exposed soil are overgrazing and the removal of crop residues for use as cooking fuel.

3. Soil erosion in forest land

In stable forest ecosystems, where soil is protected by vegetation, erosion rates are relatively low, ranging from only 0.004 to 0.05 t/ha/yr (Roose, 1998). Tree leaves and branches not only intercept and diminish raindrop and wind energy, but also cover the soil under the trees, which further protects it. However, the situation changes dramatically when forests are cleared for crop production or when pastures are developed for livestock production (Southgate and Whitaker, 1992).

D. Effects of soil erosion

1. Water availability

Water is a major limiting factor of crop productivity in all terrestrial ecosystems, because all vegetation requires enormous quantities of water for its growth and for the production of fruit. For example, 1 ha of corn will transpire about 7 million litres of water during the growing season of about three months (Pimentel et al., 2004), and lose an additional 2 million litres of water by evaporation from the soil. During erosion by rainfall, the amount of water runoff significantly increases, with less water entering the soil and therefore less water available to support the growing vegetation. On average, a corn crop of 1 kg requires about 1,000 litres of water for production while rice requires about 2,000 litres.

2. Nutrient loss

Eroded soil carries away vital plant nutrients such as nitrogen, phosphorus, potassium and calcium. Typically, eroded soil contains about three times more nutrients than those left in the remaining soil (Langdale et al., 1992). One ton of fertile topsoil or eroded fertile soil contains an average of 1 to 6 kg of nitrogen, 1 to 3 kg of phosphorus, and 2 to 30 kg of potassium, whereas the topsoil on eroded land has an average nitrogen content of only 0.1 to 0.5 kg per ton (Langdale et al., 1992).

To compensate for the nutrient losses inflicted on crop production, large quantities of fertilizers are often applied. Troeh et al. (2004) point out that the lost soil nutrients cost agriculture in the United States several billions of dollars annually. If the soil base is relatively deep (about 300 mm), and if only 10–20 tons of soil is lost per hectare per year, the lost nutrients can be replaced with the application of commercial fertilizers and/or livestock manure. However, such a replacement strategy is expensive for farmers and the country, and usually is not affordable by the poorer farmers. Not only are the fertilizer inputs dependent on fossil energy, but also the chemicals can harm human health and pollute the environment (NAS, 2003).

3. Soil organic matter

Soil organic matter is a valuable resource because it facilitates the formation of soil aggregates and thereby increases soil porosity. The improved soil structure in turn facilitates water infiltration and ultimately the overall productivity of the soil (Langdale et al., 1992). In addition, organic matter aids cation exchange, enhances plant root growth, and stimulates an increase in important soil microbes (Wardle et al., 2004). When the layer of organic matter is depleted, the productivity of the ecosystem, as measured by plant biomass, declines both because of the degraded soil structure and the depletion of nutrients contained in the organic matter. In addition to low yields, the total biomass of the biota and the overall biodiversity of those ecosystems are substantially reduced (Lazaroff, 2001; Walsh and Rowe, 2001).

Fertile soils typically contain 100 tons/ha of organic matter (i.e. 4–5 per cent of their total soil weight) (Pimentel et al., 2005), which has about 95 per cent of nitrogen and 25–50 per cent of phosphorus. Because most of the soil organic matter is found close to the soil surface as decaying leaves and stems, it is significantly reduced by erosion. Both wind and water erosion selectively remove the fine organic particles in the soil, leaving behind large soil particles and stones. Several studies have demonstrated that the soil removed by either water or wind erosion is 1.3 to 5 times richer in organic matter than the remaining soils, resulting in lower crop yield. For example, the reduction of soil organic matter ranging from 0.9 to 1.4 per cent was found to lower the crop yield potential for grain by 50 per cent (Libert, 1995).

Collectively and independently, the diverse impacts of erosion reduce crop biomass, both because of degraded soil structure and nutrient depletion.

4. Soil depth

Growing plants require soils of adequate depth in which to extend their roots. Various soil biota, such as earthworms, also require a suitable soil depth (Pimentel et al., 1995; Wardle et al., 2004). Thus, when erosion reduces soil depth substantially, from 30 cm to less than 1 cm, there is minimal space for plant roots so that plant growth will be stunted and yield reduced.

5. Biomass and biodiversity

The biological diversity existing in any ecosystem is related directly to the amount of living and non-living organic matter present in that ecosystem (Wright, 1990; Heywood, 1995; Lazaroff, 2001; Walsh and Rowe, 2001; Wardle et al., 2004). Therefore, by diminishing soil organic matter and soil quality, erosion reduces the overall biomass and productivity, which ultimately has a profoundly adverse effect on the diversity of plants, animals and microbes present in the ecosystem. Numerous positive associations have been established between biomass abundance and species diversity (Elton, 1927; Odum, 1978; Sugden and Rands, 1990). Vegetation is the main component of ecosystem biomass and provides the vital resources required both by animals and microbes for their survival.

Along with plants and animals, microbes are a vital component of the soil, and constitute a large percentage of the soil biomass. One cubic metre of soil may support about 200,000 arthropods, 10,000 earthworms plus billions of microbes (Lee and Foster, 1991; Pimentel et al., 2006). A hectare of productive soil may have a biomass of invertebrates and microbes weighing up to 10,000 kg/ha. In addition, soil bacteria and fungi add 4,000 to 6,000 species, thereby contributing significantly to biodiversity, especially in moist, organic soils (Heywood, 1995; Pimentel et al., 2006).

Erosion rates that are 10 to 20 times above the sustainability rate or soil formation rates of 0.5–1 ton/ha/yr reduce the diversity and abundance of soil organisms (Pimentel et al., 2006). In contrast, agricultural practices that control erosion and maintain adequate soil organic matter favour the proliferation of soil biota (Reid, 1985; Pimentel et al., 2006). The application of organic matter or manure also enhances biodiversity in the soil (Pimentel et al., 2006). Species diversity of macrofauna (mostly arthropods) increased 16 per cent when organic matter or manure was applied to experimental wheat plots in the former Soviet Union (Bohac and Pokarzhevsky, 1987). Similarly, species diversity of macrofauna (mostly arthropods) more than doubled when organic manure was added to grassland plots in Japan, and increased 10-fold in Hungarian farmland (Olah-Zsupos and Helmeczi, 1987).

The relationship between biomass and biodiversity was confirmed in field experiments with collards in which arthropod species diversity rose fourfold in experimental plots with the highest collard biomass compared with that in control collard plots. Reports suggest that when the biomass increased threefold, the number of species increased 16-fold. In a study of bird populations, a strong correlation between plant biomass productivity and bird species diversity was reported when a 100-fold increase in plant biomass yielded a 10-fold increase in bird diversity (Wright, 1990).

Soil biota perform many beneficial activities that improve soil quality and ultimately its productivity (Witt, 1997; Sugden, Stone and Ash, 2004; Pimentel et al., 2006). For example, soil biota recycle basic nutrients required by plants for their growth (Pimentel et al., 2006). In addition, the tunneling and burrowing activities of earthworms and other soil biota enhance crop productivity by increasing water infiltration (Witt, 1997). Earthworms, for instance, may construct up to 220 tunnel openings per square metre, which enable the water to infiltrate rapidly into the soil. Other soil biota also contribute to soil formation and productivity by mixing the soil components, enhancing aggregate stability and preventing soil crusting. This churning and mixing of the upper soil redistributes nutrients, aerates the soil, exposes it to the climate for soil formation and increases infiltration rates, thus making soil conditions favourable for increased soil formation and plant productivity. Earthworms bring from 10 to 500 t/ha/yr of soil from underground to the soil surface, while some insects, such as ants, may bring as much as 34 t/ha/yr of soil to the surface (Lockaby and Adams, 1985). Snails are reported to help the formation of 1t/ha/yr of soil.

6. Soil sediments

The long-range transport of dust by wind has implications for human health worldwide. Griffin, Kellogg and Shinn (2001) report that about 20 human infectious disease-carrying organisms, such as anthrax and tuberculosis, are easily transported by the wind in soil particles.

Soil erosion also contributes to global warming, because carbon dioxide (CO_2) is added to the atmosphere when enormous amounts of biomass are exposed and oxidized (Phillips and Helmeczi, 1987; Lal, 2002; Walsh and Rowe, 2001). One hectare of soil may contain about 100 tons of organic matter or biomass, which, if eroded, would contribute about 45 tons of carbon to the atmosphere. A feedback mechanism exists wherein increased global warming intensifies rainfall, which in turn increases erosion and continues the cycle (Lal, 2002).

7. Global climate change

Extensive burning of fossil fuels and forests appears to be increasing the level of CO_2 and other greenhouse gases (GHGs) in the atmosphere, which raises several ethical issues and choices. Clearly there is an urgent need to reduce fossil fuel consumption and deforestation to slow down the rate of global climate change. Reducing fossil fuel consumption will also conserve forests, and controlling deforestation has other benefits, including conserving biological diversity.

A large number of meteorologists and physical scientists estimate that the continued increase in CO_2 and other GHGs will warm the earth from 1.5 degrees Celsius to 4.5 degrees Celsius by the end of this century. The precise rate, extent and regional variations are difficult to predict, but negative impacts are generally projected, especially on crop production. Additional negative impacts on some crops could result from alterations in the ozone layer. Thus the overall changes in temperature, moisture, CO_2, insect pests, plant pathogens and weeds associated with global climate change are projected to reduce food production worldwide (Pimentel, 2011). The extent of alterations of crop yields will depend on specific crops and their particular environmental requirements. Hopefully, implementation of improved agricultural technologies could partially offset some of this decrease in yields. In addition, productive agriculture and an increase in soil carbon could help mitigate climate change (also see the commentary of Leu in this chapter).

In Africa, the projected rise in rainfall associated with global climate change could help improve crop yields to some extent, but it will not entirely solve Africa's food shortages, given the rapid rate of increase of its population. Water shortages are projected to persist and pests are expected to continue to result in serious crop losses (Pimentel, 2011). These factors, as well as serious economic and political problems, imply that food production in Africa is likely to remain slow.

Commentary XV: Competition for Water for Agriculture through 2050[53]

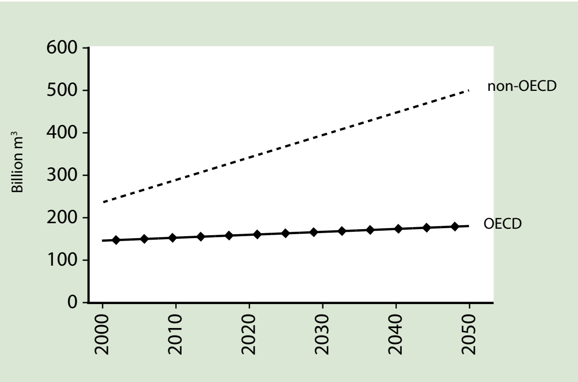
Brent Boehlert, Industrial Economics, Inc., and
Kenneth Strzepek, Massachusetts Institute of Technology

Abstract

Owing to rising populations, increasing per capita water use, environmental flow requirements, and climate change, our results suggest that by 2050 there will be significant threats to water availability for agriculture in many regions of the world. If rising agricultural demands and the full spectrum of climate change effects are taken into account, threats to water availability will be considerably more pronounced. It is therefore likely that, unless broad changes are made to the way environmental and water resources are governed, conflicts over water for agriculture will increase markedly by the middle of the twenty-first century. Changes in governance may include reforming the policies and institutions that manage and allocate water, improving access to water in the poorest regions of the world, enhancing ecosystem services, recognizing water as an economic good in order to promote efficiency of use, improving rain-fed and irrigation infrastructure to increase "crop per drop", and making agriculture more resilient to changes in climate.[54] In the light of these threats to water for agriculture, and therefore to global food availability, it is important – and urgent – that water planning efforts be coordinated and integrated across sectors, particularly in the most vulnerable regions.

Globally, 2,600 km^3 of water are withdrawn each year to irrigate crops, representing over two thirds of all withdrawals by people. As water scarcity intensifies and many of the world's river basins approach closure (i.e. all water supplies have been put to use for at least part of the year), water is increasingly transferred out of agriculture to provide for other demands, such as energy generation or growing urban populations. Given that, at current population levels, the food system is already water-stressed and global water resources are under considerable pressure, this will only intensify as populations increase further.[56] Additionally, and perhaps even more problematically, rising incomes in developing countries are causing diets to shift to more water-intensive agricultural products that require greater levels of water service, for example from community standpipes to plumbing systems. Together, these shifts are rapidly increasing per capita water demand in developing countries. Figure 15 presents these projected water use trends for OECD and non-OECD countries through 2050. Importantly, water use is projected to more than double in the municipal sector within non-OECD countries, where agriculture tends to be the most vulnerable to climate change.

Figure 15: Total projected municipal water use in OECD versus non-OECD countries, 2005–2050



Source: Hughes, Chinowsky and Strzepek, 2010.
Note: Squares with solid lines, non-OECD; diamonds with solid lines, OECD.

Simultaneously, to meet higher food demands for growing populations, agriculture is expanding to new regions and becoming more productive, which rapidly increases the demand for water. As a result, groundwater supplies, on which much of agriculture relies, are declining globally (Konikow and Kendy, 2005). At the same time, energy consumption and other industrial activities in many countries are continuing to increase, causing industrial water consumption to rise. Perhaps most importantly – and most overlooked – environmental flow requirements (EFRs) are increasingly being recognized as a crucial element of a functioning riparian ecosystem and, accordingly, are progressively being instated as part of environmental management (Falkenmark and Rockström, 2006; Smakhtin, 2008). As EFRs are established, remaining water for agriculture will be further diminished. In addition to the growing demand on water resources, climate change will significantly affect the timing, distribution and magnitude of water availability (Arnell, 1998; Milly, Dunne and Vecchia, 2005; IPCC, 2008). Where shifts in water availability reduce regional water supplies, agriculture will be further threatened.

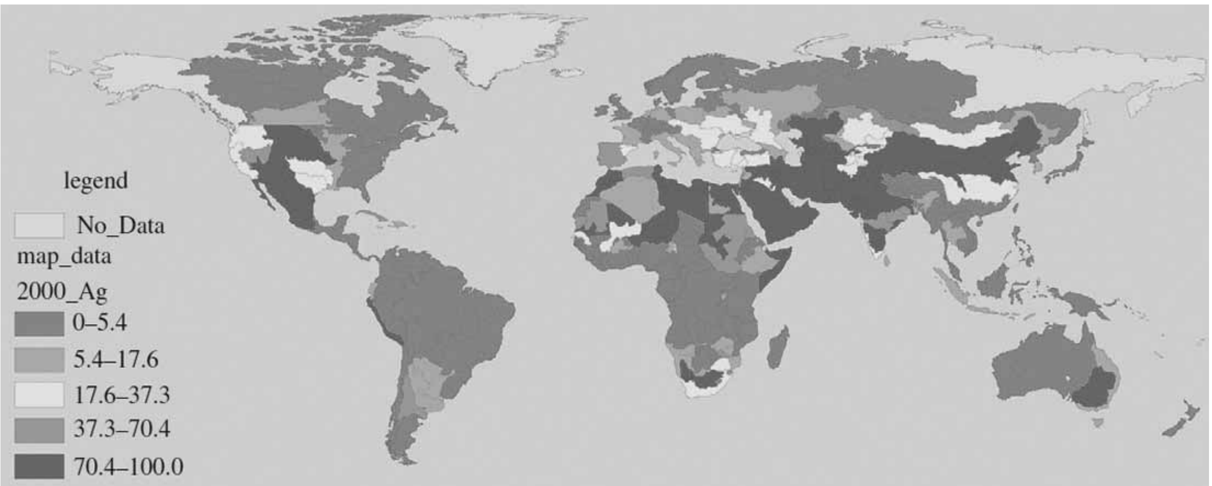
In this paper, we consider the fraction of current withdrawals from surface water systems for agriculture that may be threatened due to increasing water demands in other sectors, limits imposed on withdrawals to meet EFRs, and a range of potential climate change effects.[57] We comment on the relative importance of each competing pressure, and identify geographic "hotspots" where water for agriculture could be substantially reduced.

A. Methods: modelled threats to water for agriculture

Considering the demand- and supply-side factors that will affect the amount of water available for agriculture, we model the possible implications for agricultural water availability through 2050 under climate change. Specifically, for a number of geopolitical regions/countries, and under three climate change scenarios, we estimate the fraction of current agricultural withdrawals that would be threatened assuming that EFRs and increased municipal and industrial (M&I) demands cause total basin withdrawals to exceed mean annual runoff (MAR) in the basin.[58,59]

We consider a total of three climate change and three demand scenarios. On the demand side, we consider the effects of 2050 M&I demands alone, EFRs alone, and 2050 M&I and EFR demands together. M&I demand projections to 2050 are taken from World Bank projections for 214 countries (Hughes, Chinowsky and Strzepek, 2010). EFRs are assumed to be the basin flows necessary to maintain riparian ecosystems in "fair" condition (for details, see Smakhtin, Revenga and Döll, 2004). For the climate change analysis, we evaluate a baseline (i.e. no climate change) scenario, and two climate change scenarios based on the range of available general circulation models (GCMs). We follow the World Bank's Economics of Adaptation to Climate Change (EACC) analysis (World Bank, 2009), and model the climate change scenarios under the A2 SRES emissions scenario (see IPCC, 2009) using the global climate models (GCMs) of the United States' National Center for Atmospheric Research (NCAR) and of the Commonwealth Scientific and Industrial

Figure 16: Water withdrawals for agriculture as a percentage of mean annual runoff (MAR) in 2000



Source: Authors' calculations

Research Organisation (of Australia), which the World Bank considers to represent generally wetter and drier climate models, respectively. In total, we consider nine scenarios, each with a different climate-demand combination, and then compare each to the year 2000 baseline.

To model changes in MAR, we use the CLIRUN II hydrologic model (Strzepek et al., forthcoming), which is the latest model in the "Kaczmarek school" of hydrologic models (Yates, 1996) developed specifically for analysing the impact of climate change on runoff and extreme events on an annual basis. CLIRUN II models runoff in 126 world river basins with climate inputs and soil characteristics averaged over each river basin. Because data on 2000 agricultural and M&I withdrawals are available for 116 economic regions of the world, we intersect the 126 river basins with these economic regions to form 281 food production units (FPUs) (see Strzepek and McCluskey, 2007, and Rosegrant et al., 2009a and 2009b), which form the geographic unit of our analysis. For each FPU, our baseline data include current MAR values, 2000 agricultural withdrawals and 2000 M&I withdrawals. In 2000, roughly 10 per cent of worldwide MAR was withdrawn for agriculture, and 4.3 per cent was withdrawn for M&I use (figure 16).

B. Findings: threats to water for agriculture

We find that EFRs and increased M&I water demands together will cause an 18 per cent reduction in the

Table 4: Percentage of agricultural water threatened in the geopolitical regions, nine scenarios[a]

Region/country	Agricultural withdrawals, 2000 (billion m³)	No climate change			NCAR (wet) climate change			CSIRO (dry) climate change		
		M&I 2050 (%)	EFRs (%)	M&I 2050 and EFRs (%)	M&I 2050 (%)	EFRs (%)	M&I 2050 and EFRs (%)	M&I 2050 (%)	EFRs (%)	M&I 2050 and EFRs (%)
World	**2,946**	**7.3**	**9.4**	**17.7**	**7.1**	**9.1**	**16.5**	**7.0**	**9.1**	**16.9**
Europe	*263*	*2.5*	*7.7*	*14.4*	*2.5*	*9.6*	*12.9*	*2.8*	*16.5*	*20.4*
European Union	95	0.7	12.8	18.7	0.7	21.2	19.0	1.6	39.0	37.0
North-Western Europe	16	4.5	11.7	8.2	4.5	14.6	10.2	3.2	10.4	8.2
United Kingdom	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Former Soviet Union	186	3.2	10.0	19.7	3.2	11.7	17.4	3.7	12.3	18.9
Africa	*246*	*9.8*	*5.8*	*15.8*	*10.4*	*6.8*	*16.9*	*10.4*	*6.6*	*16.9*
Sub-Saharan Africa	50	11.9	7.2	16.4	11.9	7.7	17.6	12.1	7.3	16.6
Nile River Basin	146	9.1	0.2	9.2	9.1	0.2	9.2	9.1	0.2	9.6
North America	*255*	*-0.1*	*15.2*	*14.9*	*-0.1*	*13.8*	*13.6*	*-0.1*	*12.0*	*12.0*
Asia	*2,060*	*8.8*	*8.9*	*18.6*	*8.6*	*7.8*	*16.7*	*8.3*	*7.4*	*16.8*
China	558	2.7	7.3	10.1	2.3	4.5	6.9	2.3	4.5	6.9
India	866	13.5	12.1	27.7	13.1	11.7	25.5	12.5	10.7	25.7
Latin America and the Caribbean	*182*	*3.8*	*12.3*	*16.1*	*4.4*	*15.7*	*19.9*	*3.8*	*12.3*	*16.8*
Brazil	21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oceania	*50*	*0.2*	*14.3*	*14.5*	*0.2*	*14.3*	*14.5*	*0.2*	*14.3*	*14.5*

Note: [a] Agricultural water availability in North America increases by 0.1 per cent under the 2050 M&I scenarios. This occurs because 2000 M&I and agricultural withdrawals in North America exceed MAR in the Colorado and Rio Grande basins, but M&I declines in 2050. As a result, additional water is made available to these constrained basins.
EFRs ... environmental flow requirements
M&I ... municipal and industrial demand

availability of worldwide water for agriculture by 2050. Meeting EFRs, which can necessitate more than 50 per cent of the mean annual runoff in a basin, depending on its hydrograph, presents the single biggest threat to the availability of water for agriculture. Next are increases in M&I demands, which are projected to grow upwards of 200 per cent by 2050 in developing countries with rapidly increasing populations and incomes. The combined effect of these higher demands could be dramatic in several hotspots, which include northern Africa, China, India, parts of Europe, the western United States and eastern Australia, among others. These areas tend to be already water-stressed due to low water supplies, current large-scale agricultural or M&I demands, or both.

Table 4 displays the fraction of 2000 agricultural water withdrawals that may be threatened by increasing M&I demands and EFRs under the two climate change scenarios. Under the no climate change scenario, our models indicate that increases in M&I demands, EFRs, and combined M&I demands and EFRs will require 7.3 per cent, 9.4 per cent, and 18 per cent, respectively, of worldwide agricultural water in 2000. By volume, agricultural water in Asia accounts for over two thirds of the global total of threatened agricultural water by volume. Modelling results indicate that increases in EFRs and M&I demand together will threaten nearly 20 per cent of agricultural water in countries of the European Union and the former Soviet Union. In sub-Saharan Africa, rapidly rising M&I demands also threaten water for agriculture.

Climate change will affect the spatial and temporal distribution of runoff, and thus change availability from the supply side. Based on wet and dry climate scenarios, we find that water availability for agriculture will increase in North America and Asia, and decrease in Africa and Latin America and the Caribbean. In Europe, water availability will increase under the wet model and decrease under the dry model. Overall, these results suggest that by 2050, although the effects of climate change on annual agricultural water availability will be significant, the effects of growing M&I demands and EFRs may be even more pronounced. Importantly, these climate change results consider changes in MAR only, and thus do not account for potential changes in seasonal water availability, increases in crop water demand caused by higher temperatures, changes in the frequency and severity of extreme events, changes in yield from storage reservoirs, and a variety of other important climate change effects.

Commentary XVI: The Impact of Agrifood Supply Chains on Greenhouse Gas Emissions: The Case of a Coffee Value Chain between Tanzania and Germany

E. Krain, K. Linne and M. Gaebler
GIZ, Germany

Abstract

Agriculture is a major source of greenhouse gas (GHG) emissions, and thus contributes significantly to climate change. At the same time it has huge potential to reduce emissions, and could even contribute to capturing (sequestering) carbon dioxide (CO_2) from the atmosphere through the cultivation of tree crops. It is difficult to assess where to make effective changes without knowing facts on emission sources and quantities – you can only manage what you can measure. Therefore, methods to estimate sequestration and emissions are currently being developed and their results indicated in "product carbon footprints" (i.e. GHG emissions per unit of product). While methods vary widely, they seem to converge around the emerging ISO 14067 standard.

There are only a few practical examples of carbon footprint estimates along entire agrifood chains, but they serve as valuable case studies from which to draw some conclusions. Firstly, CO_2 sequestration estimations have generally been excluded from the equation, which discriminates against tree crop agricultural production systems. Secondly, emissions from primary production have usually been well reflected. Thirdly, results from processing and transport have tended to be smaller than was assumed prior to the analyses. Finally, GHG emissions in connection with food preparation, especially for lifestyle and convenience foods, tend to be much higher than was assumed before the studies were undertaken.

Current GHG accounting systems differ considerably in important aspects, such as in terms of whether they include or omit sequestration. If appropriate mitigation strategies are to be developed, harmonized methods are needed that should more accurately portray the overall picture, and, apart from the main sources of emissions, also report adequately on sequestration.

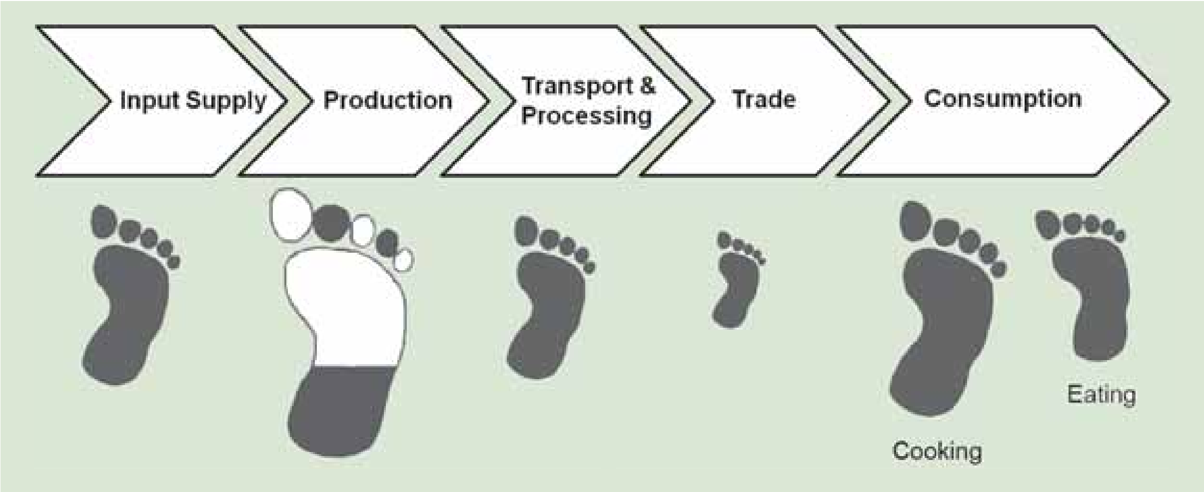
A. Introduction

The question of how to cope with climate change and reduce GHG emissions is currently high on the international agenda. Since agriculture is considered one of the key sectors contributing to such emissions, it is necessary to consider ways and means by which agricultural practices could lower emissions or even capture them (e.g. through sequestration). Lowering emissions is possible by reducing various agricultural inputs while maintaining output at the same level. This is generally understood as increasing the efficiency of a process. A second intervention is to remove GHGs from the atmosphere by, for example "sequestration", which captures CO_2 in biomass from the atmosphere. This is an option particularly suited to the cultivation of perennials (i.e. tree crops). These plants store a large proportion of the captured CO_2 as carbon in their standing and root biomass and even in their leaves and fruit, but the latter are usually quickly consumed or disposed of, thereby returning the CO_2 to the atmosphere. However, the overall balance of CO_2 stored in biomass, and over several years, may be quite substantial and worth considering in terms of climate change mitigation.

1. The generic GHG footprint of a tree crop value chain

When looking generically at a tree-crop-based value chain – from input supply to primary production, transport, processing, trade, retail and consumption – there are many stages involving GHG emissions

Figure 17: Overview of CO_2 sequestration and GHG emissions in a crop-based value chain



Source: Adapted from Krain et al., 2010.

(usually calculated in CO_2 equivalents – CO_2e) and one location where sequestration takes place (figure 17).

The light parts of the footprints in the above figure denote that CO_2 is sequestered, while the red/dark parts represent emissions. The size of the footprint indicates the volume of emitted or captured CO_2e, usually expressed in tons of CO_2e per output unit. In the above example, it is assumed that more CO_2e is captured than emitted during the primary production process, whereas high amounts of emissions occur when the product is prepared for consumption and consumed. In between, there are emissions connected with the other stages of the value chain.

In the following, the various stages from input supply to consumption are discussed briefly.

Main emission hotspots:

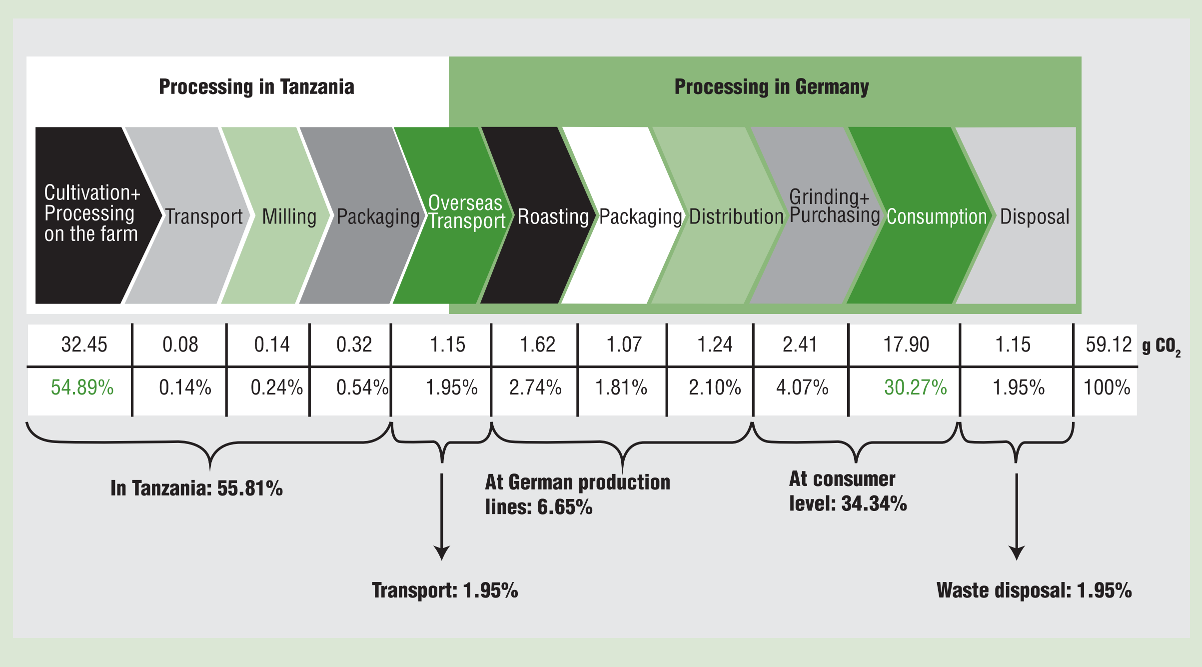
- Land-use change (especially when primary forest is converted into land for annual crop production).
- Application of agrochemicals (especially nitrogen fertilizer produced through an intensive energy-consuming industrial process and nitrogen field emissions in the form of nitrous oxide).
- Fossil fuel and energy-consuming processes during land preparation, crop maintenance, harvesting and conserving of harvests.
- Emissions from waste water (methane).
- Fossil fuel and energy-consuming processes such as industrial processing, and internal, domestic and transnational transportation.
- Finally, emissions resulting from energy consumption in food preparation at the household level.

In order to be able to decide where to reduce emissions within a value chain, it is necessary to determine how much GHG is being emitted (or sequestered) at each stage of the value chain as a basis for identifying the hotspots – you can only manage what you can measure. For this, currently there are more than 50 initiatives working on various footprinting methods and standards, such as ISO 14067, the Greenhouse Gas Protocol Product Accounting and Reporting Standard, and PAS 2050. However, so far there is no single, common calculation method, although there seems to be convergence around the emerging ISO 14067 standard, which appeared as draft in 2012. But none of the standards are product-specific and will still need to be broken down to sector/product group specific rules. Another major task still to be tackled is to develop a method that reflects the actual situation on the farm sufficiently accurately while remaining reasonable with respect to efforts and costs.

B. Some experiences with carbon footprinting in agricultural value chains

So far, for agriculture, there are only very few cases published that span an entire value chain. One such example is examined below in more detail.

Figure 18: Carbon footprint along the value chain for one brewed cup of Tchibo Rarity Machare Private Coffee



Source: Adapted from Tchibo GmbH, PCF Pilot Project Germany, 2009.

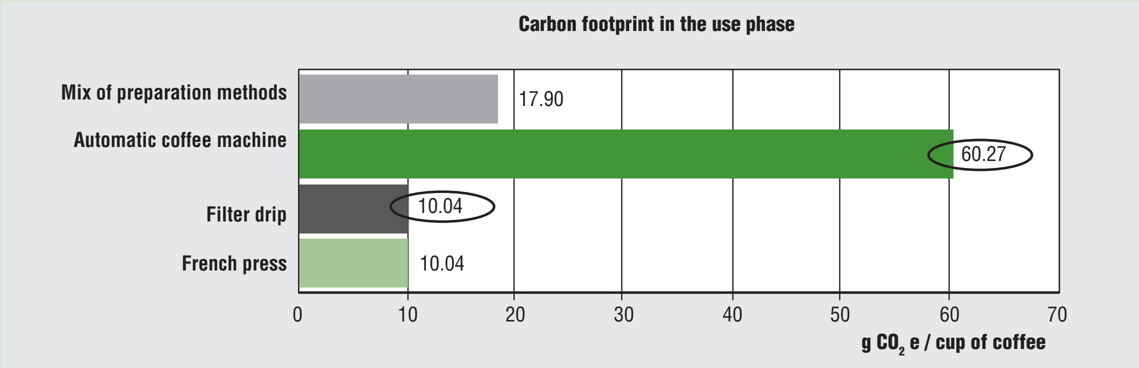
Under the Product Carbon Footprint (PCF) project Germany, various commodities were examined with respect to their GHG emissions, one of them being a rarity coffee from Machare farm in the United Republic of Tanzania. The assessments were based on ISO 14040/14044 and PAS 2050, a pioneering method developed by the British Standards Institution (BSI) to assess GHG emissions in the life cycles of goods and services.

All emissions measured in figure 18 were calculated with reference to one brewed cup of coffee containing 125 ml of water and 7 g of coffee. It shows that the major emissions occur during primary production (54.89 per cent), followed by consumption (30.27 per cent). Surprisingly, emissions from roasting (2.74 per cent) and even from international transport (1.95 per cent) were rather low. The study mentions that Machare farm is an old coffee farm and that changes in land use were not considered. Normally, emissions from land-use changes are taken into account if they have taken place within the last 20 years (i.e. after 1990). Most of the emissions were related to the application of agrochemicals. However, one important factor, namely the sequestration of CO_2 through the coffee plants, shade trees or other trees in the coffee field, was omitted. If that had been taken into account, the figures for emissions during primary production would have been significantly lower. For example, the emission balance for the Kenyan Baragwi Farmers' Cooperative Society in figure 20 shows that total GHG emissions at production stage were even negative.

The identification of consumption as a hotspot (apart from primary production) becomes even more interesting when looking at the various ways of preparing coffee.

Coffee is usually prepared for consumption in different ways, and these can have very different carbon footprints, as figure 19 shows. The study assumed a mix of preparation methods with an average of 17.90 g of CO_2e per cup. The normal filter drip method has a footprint of only 10.04 g of CO_2, while a modern automatic coffee machine – which needs a lot of energy to press the water vapour through the coffee powder – emits an enormous quantity of 60.27 g of CO_2e. If all the Machare coffee would have been prepared using only automatic coffee machines, this would have changed the total carbon footprint of the value chain to 101.49 g of CO_2e (59.12–17.90 + 60.27), with the coffee machine accounting for close to 60 per cent of all GHG emissions of the value chain! Looking beyond these figures it must be

Figure 19: Carbon footprint in preparing a cup of coffee



Source: Adapted from Tchibo, GmbH, PCF Pilot Project Germany, 2009.

recognized that because these emissions arise from energy consumption, the assumed electricity mix is another important factor in the calculations. If carbon-neutral electricity were to be used, it would reduce, or even neutralize, the carbon emissions from such processes.

This demonstrates very impressively how our modern lifestyle has become a primary source of GHG emissions. It shows that changes are needed not only in primary production, but also in consumption. It also shows where we as consumers can make a difference: do we really need to drink coffee prepared by an automatic coffee machine? And can inventive companies not produce coffee machines that require far less energy? At the same time, governments and policymakers could direct the energy sector into providing more carbon-neutral electricity. The point is that the facts need to be established so that better alternatives can be identified and effective changes made.

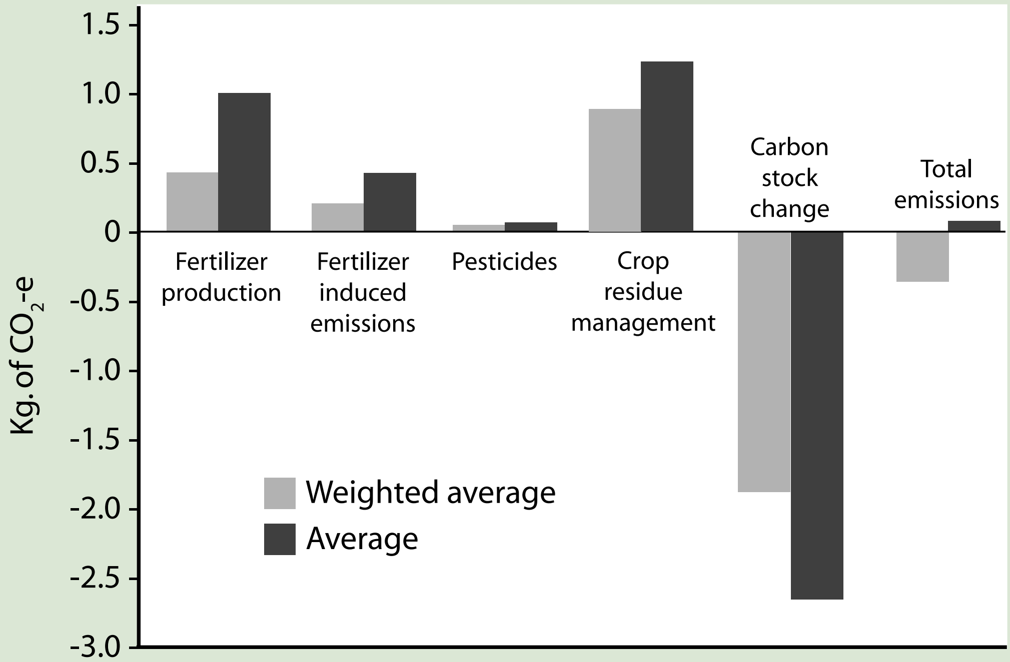
C. Reducing the carbon footprint by increasing tree crop biomass and changing cropping systems

It is unfortunate that most of the carbon footprint assessment methods omit, or do not consider, biomass creation, and thus sequestration, through tree crop systems. The underlying argument goes that, on the one hand, the amount of trees in such systems is usually small, and that, on the other hand, they will sooner or later be cut and return their stored GHG to the atmosphere.

First of all, how much CO_2 can be captured in agricultural tree crops? There are very different situations and thus data vary a lot. A mango tree can be grown with a huge canopy – as is often the case in smallholder farms – and can therefore be very similar to a forest tree, or it can be kept short and pruned, as in intensive orchard systems. Following a review of a number of reports, a general conclusion is that the amount of CO_2 captured in biomass is roughly in the order of a factor of 10 from annual crops (5–20 tons of CO_2/ha) to orchard trees (30–70 tons of CO_2/ha) and forests (550–900 tons of CO_2/ha). Thus, if tree crops in the existing farming systems were increased as much as possible over millions of hectares, this would surely considerably increase biomass and thus sequestered CO_2 accumulation. The FAO Ex-Act tool for assessing CO_2e emissions along the life cycle of a commodity takes account of sequestered carbon by trees, and has been employed successfully by GIZ in cashew tree crop systems in Burkina Faso (Tinlot, 2010). Land-use planning and agricultural strategies should make use of such a tool, as it helps determine the right strategies and incentives.

It should also be noted that once a tree dies and decays, this does not automatically mean that all the carbon goes back into the atmosphere. The soil usually harbours significant amounts of carbon, and, apart from emitting GHG, it is also able to bind and store carbon. From our own experience in Kenya (Krain et al., 2011) soils with a depth of 0 cm–60 cm contain around 180 tons of CO_2/ha – often up to 10 times more than the tree biomass.[60] Thus, farming and cropping systems, as well as their ways and methods of cultivation, differ widely with respect to their ability to sequester and store or emit CO_2. For example,

Figure 20: On-farm emissions, by category, of 25 farms in Baragwi, Kenya (kg of CO_2e per kg of coffee cherry)



Source: Linne et al., 2011.

systems involving zero or minimum tillage emit much less CO_2 than ploughing by tractor or hoe.

A recent study (Rikxoort, 2010) conducted within the framework of a GIZ public-private-partnership project on Climate Change Adaptation and Mitigation[61] showed that a coffee cultivation system adhering to a sustainability standard such as the Sustainable Agriculture Network (SAN) standard emits less CO_2e than one that uses conventional methods. In another study within this framework, conducted through the development partnership between GIZ and Sangana Commodities Ltd. in Kenya, 25 coffee farms at Baragwi Farmers' Cooperative Society were sampled in December 2010 to determine emissions and sequestered amounts of CO_2e with the help of the Cool Farm Tool (Linne et al., 2011).[62] It found that on-farm net emissions were, on average, 0.08 kg of CO_2e per kg of coffee cherries (figure 20). The weighted average, according to each farm's production volume, was -0.3608 kg of CO_2e/kg of coffee cherries. Emissions from fertilizer production and induced emissions from fertilizer use, along with crop residue management, were the primary emission sources – emission hotspots. Carbon sequestration from above ground biomass and management practices, such as incorporation of residues, compost and manure, accounted for the most significant carbon stock changes in the system, which largely offset the emissions.

D. Conclusions

Current GHG accounting systems differ considerably in important aspects, such as in terms of whether they include or omit sequestration. If appropriate mitigation strategies are to be developed, harmonized methods are needed that should more accurately portray the overall picture, and, apart from the main sources of emissions, also report adequately on sequestration.

Commentary XVII: Food Waste Reduction: A Global Imperative

Julian Parfitt, Principal Resource Analyst, Oakdene Hollins, Aylesbury, United Kingdom, and
Mark Barthel, Special Advisor, Waste and Resources Action Programme, Banbury, United Kingdom

Abstract

- Food waste is an issue of importance to global food security and good environmental governance. Yet there is insufficient reliable data from which to estimate the proportion of global food production that is wasted.
- Avoidable losses are regarded as globally significant and therefore constitute a major social and environmental burden. However, less than 5 per cent of all funding for agricultural research is allocated to post-harvest systems (Kader, 2003).

There are three particular reasons why this issue needs to be addressed with urgency:

- Some estimates suggest that waste could account for between a third (FAO, 2011e) and one half (Lundqvist, de Fraiture and Molden, 2008) of all current food production. Reduction of post-harvest waste in developing countries and consumer waste in high-income countries appear to offer the greatest potential social and environmental gains.
- The absolute quantity of food waste, although largely unquantified, will inevitably grow over the coming decades, as production increases to meet future demand and as incomes rise amongst growing populations in new megacities, notably in the BRIC countries (i.e. Brazil, the Russian Federation, India and China), and as diets become more diversified away from starchy staple foods towards fresh fruit and vegetables, dairy, meat and fish.
- Reduction of food waste would contribute to wider policy agendas that are critical to the future, namely increasing production, reducing food insecurity and food price increases, improving sustainability of the global food supply chain (FSC), reducing pressures on land use and freshwater resources and reducing greenhouse gases.

A recent review of global food waste and potential for waste reduction, carried out by the authors of this article for the Government of the United Kingdom's Foresight Programme, The Future of Food and Farming (Foresight, 2011a), provides an overview of the challenges and possible solutions for developing countries.

A. What counts as food waste?

Different ways of defining food waste reflect different research objectives. From a human food supply perspective, it can be defined as edible material intended for human consumption that is discarded, lost, degraded or consumed by pests, from harvest to consumer (FAO, 1981). From a global resource efficiency perspective, the definition might be extended to include food fit for human consumption but intentionally used as animal feed (Stuart, 2009). Currently, 40 per cent of global grain is fed to cattle (UNEP, 2009).

The term "post-harvest loss" is often used to describe losses between harvest and the onward supply of produce to markets, and equates broadly with waste in the FSC. The latter term is generally applied to post-harvest processing, distribution and retailing in high- income countries and, increasingly, in emerging economies. The FSC therefore encompasses a wide range of activities that include processing, storage, transport and distribution, manufacturing, wholesale and retail. Further upstream, there are factors at the initial, "pre-harvest" stages that also contribute to losses. For example, the capture and discarding of fish stocks before they are landed (usually resulting in their demise). Such fish by-catch represents a significant proportion of fish caught in global fisheries

(FAO, 2005). The parallel situation in agricultural systems involves losses that occur when crops are not harvested but are ploughed back into the soil. Such front-end losses are, by their very nature, difficult to measure accurately.

Losses at the consumer stage involve a complexity of human activities and processes, and encompass food wasted in the home (as a result of purchasing behaviour, food storage, meal planning and preparation, over-portioning and not using leftovers) and out of home within the food hospitality sector, such as plate-scrapings and kitchen waste.

The best environmental and socio-economic outcomes concerning food waste lie in its prevention, but failing that, options for recovering value from food waste need to be considered. These options may include supply of feedstock to lower grade markets for human consumption, or diversion into animal feed or into nutrient and energy recovery options (anaerobic digestion and composting). These routes are still considered "food waste", as the resulting benefits are small compared with the value of the original food product, and the environmental savings are generally modest vis-à-vis the cumulative environmental impacts associated with the agricultural and FSC stages of the food product life cycles.

B. Post-harvest losses in the food supply chain

In many developing countries, agriculture remains the dominant economic sector (FAO, 2009c), yet most of the rural poor rely on short food supply chains with limited post-harvest infrastructure and technologies, which contribute to substantial post-harvest losses. Cereals, the most studied food commodity group in relation to post-harvest losses (Parfitt, Barthel and Macnaughton, 2010), typically incur 40 per cent losses between post-harvest and processing stages in developing countries. The comparable data for industrialized countries suggest similar proportionate losses, but these are associated with the consumer stage (FAO, 2011e). Post-harvest losses result from spillage, poor separation and drying, contamination and consumption by rodents and insects, and fungal and bacterial diseases. At a more fundamental level, poor choice of crop in relation to climatic conditions and inadequate inputs in agriculture are often underlying factors contributing to loss (Foresight, 2011b). The losses of perishable crops, by their very nature, are higher than those of cereals, and vary considerably by region and by commodity type. Data available from low-income countries for a limited range of fresh fruit and vegetables suggest losses of over 50 per cent (FAO, 2011e). Although it has been suggested that post-harvest losses are sometimes overestimated (Parfitt, Barthel and Macnaughton, 2010), this partly relates to the difficulty of deriving "typical" loss estimates for a crop and region when the limited data from field measurements may relate to specific local research objectives, and extreme values may mistakenly be extrapolated to estimate losses from an entire country or region (Tyler, 1982; Hodges, Buzby and Bennett, 2010). Extended food supply chains in developing countries that provide food for growing urban populations are likely to involve many intermediaries between growers and consumers, which may limit the potential for growers to receive higher prices for quality produce, or even to understand what sorts of produce the market requires. The lack of price differentials and agreed quality criteria between different players in the market reduces the incentive for small producers to grade produce or to invest in suitable storage infrastructure and transit packaging. Interventions within these systems tend to focus on improving technical capacity to reduce losses, increase efficiency and reduce the labour intensity of the technologies that are used (Foresight, 2011c; Hodges, Buzby and Bennett, 2010). Attempts to reduce post-harvest losses need to take into account cultural and financial implications of any innovations in post-harvest technologies. In years with food surpluses the prices received for goods tend to be low. One option, therefore, is to store grain surpluses for lean years, but suitable storage facilities may be lacking or expensive. Investment and engineering skills are needed to provide solutions. Indeed, there are many examples of relatively simple technologies which can provide effective solutions and dramatically reduce losses (United Nations, 2007).

Looking to the future, the predicted increase in the global urban population from 50 per cent in the past few years to 75 per cent in 2050, which is expected to be concentrated in low-income and emerging economies, is likely to lead to an extension of FSCs, and consequently increase post-harvest food losses significantly (United Nations, 2008). However, infrastructural improvements, particularly dry- and cold-storage facilities, pack houses, roads, ports, telecommunications and power supplies, have the potential to counteract such developments. In some

BRIC countries, public sector investment is being considered for accelerating this process. For example, in India the Government is discussing an "evergreen revolution", which will involve the development of food processing units (Foresight, 2011c).

C. Emerging economies and high income countries

In emerging economies and high-income countries, FSCs involve closer links between growers, suppliers, processors, distribution systems and markets, thereby ensuring greater economies of scale, competitiveness and efficiency. Development of more industrialized FSCs could also foster growth in the food processing sector. In medium- and high-income countries, it has often been argued that the centralized processing of food leads to better resource efficiency and less waste overall. However, research on consumer food waste suggests that this is not the case (WRAP, 2009): consumers waste significant quantities of food, thus potentially negating the benefits of centralized food processing. Further losses are associated with cosmetic quality standards applied by retailers to fresh fruit and vegetables, which can reduce the volume of marketable and edible food reaching consumers. This trend is increasingly being counterbalanced by the growing influence of retailers and manufacturers in agricultural development groups, crop sustainability groups and sustainable agriculture initiatives, all of which are bringing about improvements in growing practices and further reductions in post-harvest losses.

In emerging economies, supermarkets are the main vehicle for providing diversified diets for the expanding middle classes and the urban poor. These developments are almost entirely dependent on foreign direct investment, and show high growth rates in Eastern Europe, parts of Asia and Latin America (Reardon, Timmer and Berdegué, 2007). The nature and pace of these developments are influenced by the extent to which retailers bypass existing markets and traditional wholesalers to secure produce of the required standard and volume. Many of the factors that may increase waste identified in the FSCs of emerging economies are similar to those in high-income countries, such as payment terms that discourage small growers, and systems for demand forecasting, order planning and replenishment that sometimes lead to overproduction.[63] However, there are lessons that might be learnt from industrialized countries. For instance, the combined effects of contractual penalties for non-delivery of order volumes, residual shelf-life product take-back clauses and poor demand forecasting were estimated to drive up overproduction and higher levels of wastage by 10 per cent in the United Kingdom FSC (Defra, 2007).

D. Food waste by consumers in low-income countries

To date, there are little published robust data on the scale of consumer food waste in low-income countries and emerging economies. However, a conclusion from a recent workshop on global food waste prevention (Foresight, 2011c) was that, overall, the scale of consumer waste appears to be lower in these countries, but in some of the emerging economies, particularly Brazil and urban China, it seems to be approaching that of the OECD countries. In much poorer communities, there is typically a wider range of outlets for discarded food, and these cultures commonly arrange for the most hungry and destitute people to obtain leftover food scraps. The net loss to human consumption can therefore be lower, albeit with higher safety risks, particularly if the water used for food preparation is insanitary.

E. Conclusions: low-income countries show the greatest potential for food waste reduction

A significant reduction in global food waste is an important step towards securing food for the growing global population, which is estimated to exceed nine billion people by 2050. The potential to meet the resulting increase in demand cannot be met through further productivity gains alone, or by extending the area of land for agricultural production. It is therefore essential to obtain more from global food production by wasting less. This will require action on many fronts, across high-income and lower income countries alike. The *Foresight Review* (Foresight 2011d) identified the main actions needed in order to bring the maximum benefit to developing countries. These are briefly discussed below.

Greater investment in storage, packaging and transport infrastructure in low-income countries by national governments and the donor community. Relatively low-cost interventions that could achieve sizeable food waste reduction include: basic packaging for transport of fresh produce, innovation in low-technology storage to reduce grain losses on small farms, and simple cool chain options that are not fuel-intensive. These investments could potentially increase the income of participants in the food chain, including growers, particularly if they enable access to more remunerative markets. In addition, the evidence shows that domestic or international markets and effective local policies aimed at upgrading activities and food standards are crucial to achieving success (FAO, 2003; Kader, 2005).

Connecting smallholder growers in low-income countries to urban/regional and international food chains through better infrastructure, and possibly linked also with various forms of ethical trading. Substantial investment in infrastructure is needed to reduce post-harvest losses and to provide smallholder farmers with better access to markets, with lower transaction costs and better returns. The use of communication technologies (mobile phones in particular) for improving market information and access to other important services (e.g. weather forecasts, locally appropriate crop varieties, good agricultural practices) would enable producers to make better planting, harvesting and supply decisions, meet market requirements and avoid, or at least reduce, seasonal gluts and higher wastage rates (Foresight, 2011c).

Targeting of aid budgets to encourage small growers to produce improved quality produce for local and regional markets in a similar way to the United Nations World Food Programme's Purchase for Progress initiative,[64] which includes the provision of guaranteed contracts, agricultural extension services and crop insurance for local communities, and a social safety net, as well as food aid from local rather than international sources. Such measures help to reduce post-harvest losses as they encourage investment in post-harvest infrastructure and reduce price fluctuations.

Encourage training in the sciences relevant to food storage and distribution in low-income countries through dedicated programmes and bursary schemes. This should include the training of people to support the planning and maintenance of the more advanced post-harvest and FSC technologies needed to feed growing urban populations.

Development of a global benchmarking network to estimate food losses, with priority given to emerging economies. Much of the data available on losses have not been collected systematically, and there are few up-to-date direct field measurements. If progress is to be made towards a global benchmark for food waste, more empirically based loss estimates are necessary. Such an undertaking would require strong leadership in international agencies with an interest in food security and development issues. Given the wide variability of FSCs, it would be unrealistic to gather data from a representative sample of the global FSCs. A more targeted approach has greater chance of success, with priority assigned to those systems likely to experience higher wastage rates, and focusing on the most critical FSC stages, such as from farms to distribution centres for fresh produce in emerging economies. Selected supply chain segments should be monitored to establish how changes in technology and infrastructure have influenced losses.

Commentary XVIII: The Role of Sustainable Consumption in Fostering a Fundamental Transformation of Agriculture

Lucia Reisch
Copenhagen Business School, Denmark

Abstract

- Major changes in food behaviour towards more sustainable consumption systems must happen, in particular in the industrialized countries.
- Key issues of concern are excessive meat and dairy, sugar and fat consumption in "modern diets", overconsumption in some parts of the world and underconsumption in others as well as food waste.
- In order to foster sustainable food consumption, it is necessary to coordinate policies relating to food, the environment, health and social cohesion.

A. Definition of sustainable food consumption

The Oslo Roundtable on Sustainable Production and Consumption has defined sustainable consumption in general as: "the use of goods and services that respond to basic needs and bring a better quality of life, while minimizing the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not to jeopardize the needs of future generations" (Norwegian Ministry of the Environment, 1994). As regards consumption in the food domain, there is no broadly accepted definition to date, but several attempts to clarify and sharpen the concept have been made. Definitions differ depending on the thematic focus – environment and climate, public health and life opportunities, malnutrition and critical access to food. Still, a core set of criteria can be distilled. Perhaps the most encompassing approach has been introduced by the Sustainable Development Commission (2005) of the United Kingdom. The commission considers food and drinks sustainable if they:

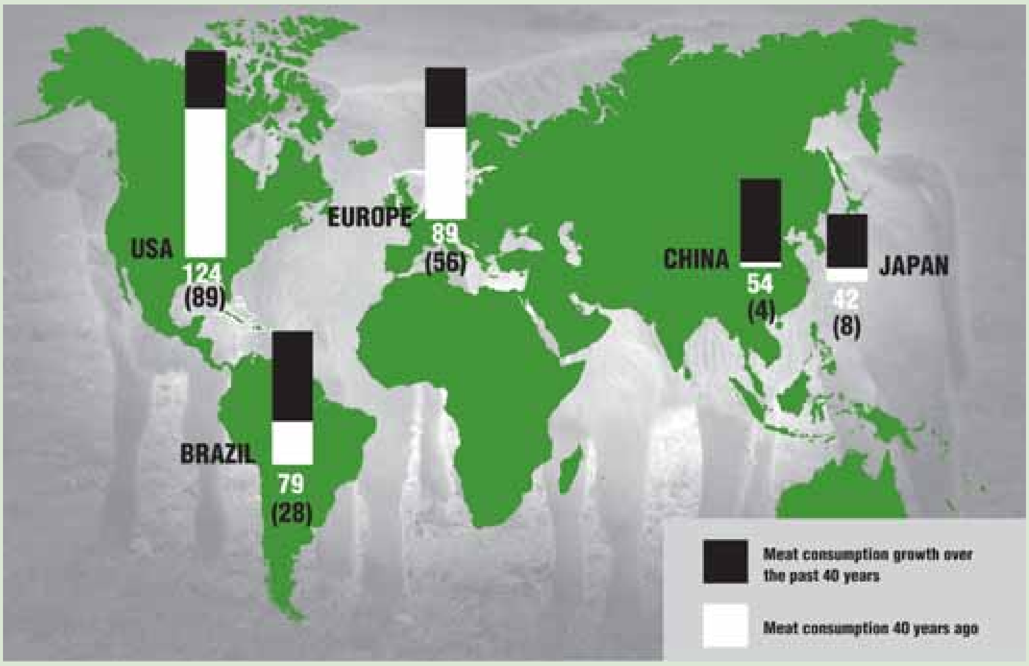
- Are safe, healthy and nutritious, for consumers in places such as shops, restaurants, schools and hospitals;
- Can meet the needs of less well-off people;
- Provide a viable livelihood for farmers, processors and retailers, whose employees enjoy a safe and hygienic working environment, whether nationally or abroad;
- Respect biophysical and environmental limits in their production and processing, while reducing energy consumption and improving the wider environment;
- Meet the highest standards of animal health and welfare, compatible with the production of affordable food for all sectors of society; and
- Support rural economies and the diversity of rural cultures, in particular through an emphasis on local products that keep food miles to a minimum.

Definitions from a social science perspective highlight the importance of the socio-cultural dimension – the necessary "fit" of food patterns with people's everyday lives – for developing effective policies (e.g. Hayn et al., 2006). Here, food consumption is considered sustainable only if it:

- Is environmentally sound (with regard to water, soil, climate, biodiversity, avoidance of unnecessary risks);
- Is health promoting;
- Allows for socio-cultural diversity; and
- Is applicable in everyday life styles.

From a worldwide perspective, the question of fair distribution and access to healthy and safe food – discussed under the key term "food security" – comes to the fore. Achieving sustainable consumption of food requires confronting problems of both underconsumption and overconsumption. As regards the former, 1.3 billion people exist on incomes of $1 a day or less, and over 800 million people are hungry or starving. Yet the problem of food security goes beyond

Figure 21: Growth rate of meat consumption over the past 40 years (kg/person/yr)



Source: Compassion in World Farming Trust, 2004: 3, based on data from FAOstat.

that of hunger and access; it also covers the problem of "hidden hunger" (i.e. deficits in vital micronutrients), which, according to a WHO estimate, affects about 1.2 billion people worldwide. At the same time, there is a worldwide increase in the number of people who are overweight or obese, both in developing and affluent industrial countries.

While the environmental impacts of food consumption and production have been debated since the 1990s – with a focus on greenhouse gas (GHG) emissions – the connections between climate/environment and health have only recently become a concern in political documents (e.g. Health Council of the Netherlands, 2011). According to this approach, a systems perspective of sustainable food consumption seems to replace the traditional "silo perspective" of separate sustainability dimensions prominent in many national policies. In 2010, the European Commission listed the following criteria for diets to be considered as having a "health value":

- Nutrient and energy content (nutritional value),
- Natural food properties ("aesthetic/gustatory" and "digestive"),
- Ecological nature of food production (sustainable agriculture),
- Health and toxicological criteria (food safety).

As regards the latter, consumers' perception of food safety is clouded by unhealthy food additives, toxic residues and other by-products, as well as potential risks from genetically modified and nano-technologically enhanced foods. This provides a major impetus for the growth of organic food sales.

Based on a broad understanding of sustainable consumption, as reflected in the definitions cited above, we define sustainable food consumption as a choice of food which is beneficial and life-enhancing for individuals, society and the planet. However, sustainable food consumption in such a comprehensive sense is seldom considered in policy-making. The following section illustrates why major changes in food behaviour towards more sustainable consumption systems must take place, particularly in industrialized countries.

B. Main problematic trends and needed changes

Given the growing world population and demographic change, problems are predicted to become more serious in the future; for example, agricultural production must face the impacts of climate change, conflicts over land use are predicted to increase, and health and social costs – both at the individual and social level – will rise because of food-related health threats. A key ethical issue is ensuring food security for the worlds' growing population – a goal that will not easily be achieved. In many developing countries, shortage of drinking water will also be a major problem. To meet the needs of a growing world population and the increasing demand for meat in developing countries, particularly in China and India (figure 21), there would have to be an exponential growth in land use for agriculture, while at the same time the most productive cereal producing areas in China, India and North America will be approaching their biophysical limits (Tempelman, 2006).

The reasons for this unsustainable development pattern include the industrialization and globalization of agriculture and food processing, consumption patterns that are shifting towards more meat and dairy in diets, modern food styles, an abundance of food on the one hand and a lack of food security on the other, and the continuously growing gap between rich and poor on both a worldwide scale and within individual societies. These factors are the result of national and international policies and regulations, business practices and particular values. The main problematic trends and needed changes are discussed below.

In industrialized countries, there is a wide range of available food products. Because most food products are available at affordable prices year round, food seasonality has lost its meaning. Besides an abundant choice of healthy fruit and vegetables throughout the year, consumers in most EU countries benefit from comparatively low prices and considerable convenience, which have accompanied changes in food production and globalization. A major drawback in this progress, however, is that consumers have become increasingly estranged from the production of their foodstuffs, and, despite the recent recurrence of interest in regional foods and new trends such as slow food and organic produce, consumer knowledge of seasonality or regional supply has been lost (see, for example, Tischner and Kjaernes, 2007; Blay-Palmer, 2008).

At the level of the individual, food habits and preferences are shaped by cultural traditions, norms, fashion and physiological needs, as well as by personal experience with and exposure to specific foods and their supply (i.e. availability and accessibility of foodstuffs). Such preferences and tastes, together with finances, time and other constraints (e.g. work patterns, household decision-making), influence food consumption. Price, in particular, is a major determinant. Food preferences also differ significantly by household-specific characteristics such as age, income, education, family type and status in the labour force, as well as nationality (European Commission, 2006). Researchers have therefore made an effort to cluster consumers into groups that represent different "nutrition styles" or "food styles" so that they can be targeted with messages about "proper food" (Michaelis and Lorek, 2004; Friedl et al., 2007; Schultz and Stieß, 2008).

The following observable developments and trends in food consumption in many OECD and most EU countries are problematic with regard to sustainable food consumption (Reisch, Scholl and Eberle, 2010):

- *Changes in diet.* Particularly in OECD and EU countries, there is a trend towards higher consumption of meat (especially pork and poultry), cheese and bottled drinks, and a declining consumption of milk and potatoes (OECD, 2001; European Environment Agency, 2005).
- *Weakening of nutritional competencies despite increasing knowledge of healthy nutrition.* Competencies in nutrition and home economics (i.e. cooking and food storing, and financial competencies) have declined. At the same time, knowledge of healthy foods and healthy nutrition has increased.
- *A decline in time spent on nutrition*. Time spent on food purchasing and cooking, as well as on eating, has decreased significantly over the past few years. In general, however, women still spend more time than men on food purchasing and cooking (Hamermesh, 2007).
- *A decline in relative consumer spending on food*. Although absolute household expenditures on food increased during the 1990s in many EU countries,[65] the average share of expenditure on food in total household expenditure in European households has declined steadily with rising incomes (Michaelis and Lorek, 2004; European Environment Agency, 2005). For many consumers, price is the dominant criterion in food purchase, followed by quality, freshness, (long) shelf life and taste.
- *An increase in convenience, readymade and fast foods and out-of-home consumption.*[66] In addition to a tendency towards consuming highly processed foods (fast and convenience food), consumption of readymade meals is continuing to rise within the EU (RTS, 2006). Out-of-home consumption also

accounts for a significant and growing proportion of European food intake; for example, in 2002 one fourth of meals and snacks were eaten out (Michaelis and Lorek, 2004).

- *Increasing diet-related uncertainty on the part of consumers.* A decade of food scares, together with differing expert evaluations of risk, contradictory and short-lived nutrition-related information in the media, a greater variety of available foodstuffs, and the globalization and distancing of food production have produced growing consumer uncertainty about food (Bergmann, 2002). Indeed, rather than helping consumers navigate the vast array of information about food, the multitude of food labels has led to consumer confusion and information overload that prevents them from quickly finding relevant key information (Derby and Levy, 2001; Hawkes, 2004). As a result, (re-)building consumer trust in the information about food provided by both the State and the market is a major challenge (Kjaernes, Harvey and Warde, 2007).
- *Problems of overweight and obesity in spite of increasing health awareness.* In most industrialized countries, the wealth of available food, combined with increasingly sedentary lifestyles and modern diets, is leading to rising obesity levels. In these countries, the rise in adiposity (i.e. fat-storing body tissue) is occurring particularly among children and teenagers, but is also evident among lower socio-economic groups (WHO, 2005; Reisch and Gwozdz, 2010). In developing countries, obesity is mostly a problem among the well-off (Witkowski, 2007).
- *Complexity of food choices.* The above developments in food supply have greatly increased the complexity of food choice: the more options and novelties on offer, the more complicated it becomes to find the right information and the more complex the decision-making process. Although information brokers – from testing organizations to food magazines to Web 2.0 Slow Food communities – may be able to reduce such complexity for a few people, many consumers remain overwhelmed and prefer to stick to their habitual choices (Mick, Broniarczyk and Haidt, 2004). The success of food discounters such as Trader Joe's in the United States, which offers a very narrow food assortment, is due to an attractive mix of few choices (and hence, low search costs) and their provision of standard quality organic products sold at fair and low prices. This is in contrast with what established super- and hypermarkets offer.
- *Increasing food waste.* Today, large quantities of food are wasted, particularly by food retail firms and consumers. For instance, according to one recent study, households in the United Kingdom waste one third of the food they buy, 61 per cent of which could have been eaten if it had been better managed.

Much hope is pinned on the increasing consumer interest in organic and fair trade foods. The markets for organically grown products and for fair traded food products have grown steadily (Krier, 2005; Willer, Yussefi-Menzler and Sorenssen, 2008). Nevertheless, the market share remains low, with organic food accounting for 0.5–5 per cent (Willer, Yussefi-Menzler and Sorensen, 2008) and fair traded food for less than 1 per cent of the total food market (Krier, 2005). Also, turnover is stagnating in many markets because of a fall in the prices of non-organic foods and an increase in price competition.

C. Towards a policy of sustainable food consumption

On the demand side, national governments generally play a relatively weak role. To date, the main driver behind regulatory command and control instruments relating to food consumption and production is the need to respond to acute threats to the life and health of citizens. It is only for the past few years that government concerns about food intake have broadened to consider everyday diet and health issues. These concerns (especially as they relate to obesity and its health impacts) are slowly resulting in policy actions, but most of these measures are only designed to provide information, and rarely take the form of regulation. Command and control is usually applied in cases that can be left neither to voluntary agreements nor to the market because of the high risks involved, or because of time pressure and doubts about the effectiveness of voluntary agreements. Thus, regulation concentrates on food safety issues, and aims to protect consumers' health, their lives (e.g. standards of hygiene) and their economic interests (e.g. competition policies).

With regard to sustainability in the food sector, governments and their administrations generally become involved only as organizers of (public) certification, standardization and inspection schemes. One example of this role is evident in the State-run labelling of organic and regional foods observable in about half of all EU countries (Organic Europe, 2010). Such labels constitute an important tool for raising consumer awareness about the health and environmental aspects of their food and for facilitating informed decision-making.

Another relatively recent approach to promoting sustainable food consumption is self-regulation in the form of public procurement of sustainable food (or guidelines for procurement) for public insitutions, such as kindergartens and schools, staff canteens in the public sector, prisons and hospitals. However, examples from various EU member States – especially the United Kingdom and Sweden – demonstrate that such self-regulation requires time and effort, and seems to be effective and improve the quality of the food served only when the initiatives are closely monitored by the governments (Sustain, 2010). A recent report concludes unambigiously that "the only way to achieve a radical improvement in public sector food – for example in our schools, hospitals and care homes – is for government to introduce a new law which sets high, and rising standards for the food served" (Sustain, 2010: 2).

Market-based instruments targeting households and individuals seem to be less prevalent in the food domain, though they are applied upstream in the food supply chain (e.g. subsidies to organic farmers). Very recently, initiatives have been launched to tax certain food types, such as "junk food" in Hungary, or their ingredients, such as a tax on specific types of fat in Denmark.

The dominant policy instrument in the food domain is an information-based and educative focus on raising awareness. This is often accompanied by voluntary instruments of self-commitment, cooperation and networking. While efforts to educate consumers, especially young consumers, in growing, processing, cooking and storing food are declining in most societies – due to the increase in out-of-home and readymade food consumption, and in other priorities in formal school curricula – there are some ongoing efforts to develop "food literacy" among young consumers with regard to choosing and preparing healthy (e.g. more fruit and vegetables) and sustainable (i.e. organic, regional, fair-trade) food. As one element of a national food strategy, France has recently started to systematically train the sensory and taste competences of schoolchildren.

The achievement of behavioural change in favour of more sustainable food consumption is a long-term goal that requires constant and continuing efforts of all the actors involved. Barriers are evident at the institutional, informational, infrastructural (i.e. the availability, affordability and accessibility of a sustainable supply) and personal levels. Government support for sustainable food entrepreneurs and community-based food initiatives could help make the sustainable choice easier (and more affordable).

A substantial barrier to effective consumer information and education is the disturbing fact that scientific evidence is not conclusive, and that some recommendations to consumers, such as the recommendation that organic or local products should always be preferred to conventional or imported products, might not be well-founded. "Organic" and "local" are two pillars of sustainable food consumption that have recently been challenged by scientific reports (e.g. Reinhardt et al., 2009).

Available research generally agrees on the issues giving rise to the lack of sustainability of the current food domain (Reisch, Scholl and Eberle, 2010): the distance between food consumers and producers (in miles as well as minds), the significant loss of biomass from the field to the table (including generated waste), and the high level of consumption of animal products in the form of meat and dairy products. Consequently, these are the critical aspects of non-sustainability that governments need to address as a priority.

Despite the growing attention paid to food issues at the policy level, approaches that integrate the different sustainability issues into coherent policy approaches or action plans – or at least into policy tools that do not contradict each other – are hard to find. The same is true for explicit strategies for sustainable consumption. Policies relating to nutrition and food, the environment, health and social cohesion are seldom coordinated. Furthermore, explicit policies for sustainable consumption, in general, and for food consumption, in particular, are rare. Policy tools are usually designed one-dimensionally for specific policy domains, and adopted policy tools primarily target individual consumers.

As a result of the current power structure in the European food domain, which is characterized by a dominant, highly concentrated, powerful retail industry, governments tend to limit themselves to a marginal role and to non-invasive instruments, such as consumer information and education. Another reason for the reluctance to implement strict national food policies is that sustainability goals and policies risk conflicting with European laws. For instance, the EU has recently requested that Sweden withdraws its National Food Administration's (NFA) proposal to the EU on guidelines for climate-friendly food choices because they may conflict with European trade goals. The EU Commission found that the recommendation to eat more locally produced food contravenes the EU's principles of free movement of goods.

Governments also struggle to understand the definition of sustainable food and sustainable diets, and they often have no real vision about the possible forms that sustainable food systems might take. As a starting point, an understanding of the difference between sustainable *food* and sustainable *diet* seems to be crucial. For instance, one can eat very healthy, sustainably produced food, but simply eat too much or too little of it. Alternatively, food could come from sustainable farming, but it could still be highly processed and over- packaged. Hence, a priority for governments should be to develop *integrated, cross-sectoral, population-wide food policies* on such issues as agriculture and food supply, availability and access to food, physical activity, welfare and social benefits, fiscal policies, animal welfare, and information and social marketing (Robertson, Lobstein and Knai, 2007).

A review of current European sustainable development strategies and action plans highlights the following major goals regarding sustainable food consumption (in order of priority):

- Lowering obesity levels and increasing health,
- Increasing organic food consumption and production,
- Reducing GHG emissions, and
- Reducing food waste.

As sustainable development strategies are a result of societal debates in the various countries, they reflect mainstream thinking about the areas in which policy instruments are appropriate and necessary. However, these explicit goals neglect other relevant aspects of food and drink sustainability: the social and economic dimensions in both the global and local sense. The United Kingdom's Sustainable Development Commission (2008) emphasizes the need to move beyond reflections on "safe, healthy and nutritious food" to include consideration of "the needs of the less well off". That is, it is necessary to consider decent economic, living and working conditions of those working along the food chain, respect for animals, support for rural economies and cultural aspects.

Another issue is reflected in recent discussions in academic circles that has not yet received sufficient attention from policymakers: self-sufficiency of countries in terms of food supplies, and the uneven impacts of food production on the soil. This is a rather complex issue which is made all the more challenging by WTO rules and EU policies that promote international trade above all else. However, it is an area that needs to be carefully analysed (for a more elaborate discussion, see the lead article and the commentary of Chemnitz and Santarius in chapter 5 of this Review).

The above-outlined requirements appear to be relevant for building a framework for sustainable food consumption and production: short-term action on the agreed problems and medium-term specification of how to redesign food systems (Reisch, Lorek and Bietz, 2011). A parallel debate on a "European food model" and its common values (for example, as regards genetically modified organisms and nanotechnologies) is also necessary. Such a debate should include the possibility of a "green economy" strategy for the food sector.

However, developing such integrative strategies and identifying the most sustainable way to ensure the nutrition of the world's current and future populations requires further research. More research is also needed on ways to achieve sustainable food consumption patterns. The overwhelming view in the scientific literature is that the most effective ways for affluent societies to reduce the environmental impact of their diets are to cut down on the amount of meat and dairy products consumed, especially beef, buy organic, seasonal and locally available food products, and avoid products transported by aeroplane.

Over and above these concerns, governments should develop cross-sectoral, population-wide policies on a variety of issues, including those relating to agriculture and food supply, availability of and access to food, physical activity, welfare and social benefits, sound environmental production and consumption, fiscal policies, the role of individual consumer decision-making, public procurement and public provision of food. Based on these policies, governments should develop action plans on sustainable food consumption.

Current food consumption patterns not only threaten the quality of life of individuals; they also have negative environmental, social and economic impacts. Policies and programmes to counteract these impacts are complicated because of the multiple interdependencies between the actors and issues involved in the food system. While useful and useable consumer information on the consequences of food consumption, early consumer education and case-based consumer advice can empower consumers, better knowledge will not automatically change preferences and behaviour. Rather, availability, affordability and social attraction of sustainable food choices, as well as easy access to them, seem to be the key levers to foster sustainable food consumption by individual consumers. "Making the sustainable choice the easy choice", promoting healthy foods, rethinking menus in canteens and simplifying food labelling are worthwhile policy initiatives to explore, keeping in mind the diversity of social settings and welcoming cultural diversity in food consumption.

Commentary XIX: Food Safety and Systemic Change: Limitations of Food Controls for Safeguarding Food Safety

Jutta Jaksche, Policy Officer Food
Federation of German Consumer Organisations (Verbraucherzentrale Bundesverband, VZBV)

Abstract

Increasing globalization has accelerated the industrialization of agricultural practices and cost pressures among producers. This has led to larger scales of production of a very limited number of commercially lucrative agricultural goods in a decreasing number of production units, with several unresolved food-safety risks that are difficult to manage.

In the absence of effective regulation, production standards in globalized markets will follow a "race to the bottom" with the result that in terms of environmental, social and ethical criteria the cheapest and lowest standards might be applied.

Although there are comprehensive control mechanisms to ensure food safety, they are insufficient to guarantee food safety for all internationally traded products. What is lacking is a proactive, preventive approach.

The current approaches to assuring food safety are complicated and expensive, especially for small-scale producers, and in the end producers and consumers pay the additional costs. The notion that more controls are sufficient to guarantee adequate food safety has proved wrong: additional controls have not been able to halt or reverse the trend of increasing contaminants in food products and greater environmental pollution. A systemic change towards low-risk, sustainable production techniques will ease the problems of food safety and may also improve the level of trust of consumers in agricultural products.

A. Changes in consumption habits in a globalized world

Consumers in the European Union (EU) are able to consume foods from all over the world during virtually any season of the year. This is possible because of world trade which has become more and more interconnected in the globalization process of the past few decades. But globalization is partly blind to many social and environmental impacts of production, because of cost pressures and resulting scale requirements.

Race to the bottom takes place because good social and environmental conditions lead to higher costs. If there is no transparency for consumers or no other limitation "a race to the bottom" is going to be the overwhelming model for investment.

For example, Western demand for imported animal feed drives the production of soybeans, corn and wheat overseas and leads to non-site-specific production schemes. The European agricultural and food sector is highly dependent on feed imports, which enable it to be the world's biggest exporter of food products.

According to estimates of a German group of associations, coordinated by the Arbeitsgemeinschaft bäuerliche Landwirtschaft (AbL) and the EuroNatur Stiftung (2011: 8), "the EU's need for agricultural lands outside of the Community (including some 19 million hectares for the production of imported soy and protein feeds) is estimated to be in the order of 35 million hectares – this is twice the utilized agricultural area of Germany."[67] The relationship between feed, livestock and animal manure has been neglected, with negative effects on the environment, ground water, oceans, biodiversity, animal welfare and public health. Livestock production now needs to be re-linked to locally available agricultural land and de-linked from being a direct competitor of human food supply.

Another trend concerns the de-globalization of food chains. In a survey of consumers, which asked them to what extent they were concerned about food safety in global supply chains, 37 per cent replied that they were very concerned, while 42 per cent responded that they were somewhat worried (European Commission, 2010).

There is growing consumer preference for regional products over products from very distant countries of origin. According to a survey by Nestlé (2011) the attractiveness of regional products has exceeded that of organic farming: 81 per cent of respondents claimed they bought regional food, and of these, 37 per cent reported buying regional food on a regular basis, whereas 44 per cent reported buying it from time to time. The motivations for such consumer preference are their belief that these products are of better quality, they feel more secure when knowing about the origin of the products, and their desire to promote sustainability and the local economy. This is also why consumers like to see the place of origin marked clearly on food products.

The past few decades have witnessed a massive change in production as well as in processing and consumption habits. Knowledge on how to prepare food has been lost, and convenience foods and eating out as a result of time pressure have become increasingly popular. Costs of food packaging often exceed the costs of the foods themselves.

B. Sustainable agriculture

Often food safety measures, such as inspection of food and recalls of tainted food, take place at the end of the food chain. While these measures are indispensable, more important should be prevention, both for reducing related transaction costs and for gaining the trust of consumers. Prevention in the context of food safety means starting at the initial stages of production: looking into the use of resources and the mode of agricultural production. It is now well known that intensive use of fossil fuels in agriculture will not be sustainable in the future; neither will the use of other resources, such as phosphate and phosphorous. But systematic change is necessary not only because of the eventual scarcity of these external inputs, but also because of problems with assuring food safety in highly intensive conventional agricultural production systems.

It is clear that while efforts are being made to combat animal diseases and product contamination in agricultural production systems, not enough is being done to prevent them. This leads to negative and unsustainable interdependencies between agricultural production and public health, as illustrated by the example of antibiotic resistance. The European Food Safety Authority (EFSA) evaluated the public health risk of bacterial strains resistant to certain antimicrobials in food and food-producing animals. It drew the conclusion that the use of antimicrobials in food-producing animals was a risk factor for the spread of those bacterial strains and for public health. As a result of this study experts recommended imposing restrictions and banning certain antibiotics (EFSA, 2011).[68] The experts also concluded that the extensive intra-EU trade in animals was an additional risk factor for antibiotic resistance.

There needs to be greater attention to combating and avoiding global epidemics – so-called pandemics, many of which are zoonoses (i.e. diseases which can be transmitted from animals to humans). A paper by the European Commission's Directorate General for Health and Consumer Affairs (SANCO, 2011) defines prevention as consisting of measures to decrease occurrence and transmission of animal diseases by farming and food chain practices and animal transport, in order to ensure a high level of animal health, public health and food safety. This includes limiting the incidence of zoonoses in humans and other biological risks. SANCO estimates that the cost for a vaccination bank at EU level, maintaining only the vaccines for foot and mouth disease, is about €1.4 million per year. The total value of the antigen stored in a vaccine bank is estimated at €10.6 million from 2012 onwards, and the stock has to be renewed every five years.[69] According to the SANCO study, the main tools and instruments of prevention are monitoring and surveillance in member States and biosafety measures such as disinfection, segregation and cleaning. (For a critical discussion of biosafety, see Idel and Reichert in chapter 2 of this Review.) In the event of an animal disease breaking out, prevention and control strategies include import restrictions, such as legislation and control of animal movements across national borders. However, what is missing is a discussion of the limits of animal transport and the density of animal production to avoid outbreaks and to maintain production at a level commensurate with regional market requirements and environmental carrying capacity.

First of all, we need a concept for sustainable agricultural production, and not only for Europe.

This has to be defined according to site-specific conditions. Researchers have defined critical "planetary boundaries" to ensure human safety, the transgressing of which could be catastrophic. (Rockström et al., 2009) Nine of the boundaries identified are climate change, stratospheric ozone, land-use change, freshwater use, biological diversity, ocean acidification, nitrogen and phosphorus emissions into to the biosphere and oceans, aerosol loading and chemical pollution. According to a report by Rockström et al. (2009) three of the nine boundaries have already been transgressed, all of them connected with agricultural production.[70]

The German Council for Sustainable Development (2011) recommends that the organic farming concept be made the gold standard for agricultural production, to be used as a guideline, though it needs to be continuously developed. Dusseldorp and Sauter (2011) also note that low-external-input agricultural practices in developing countries have resulted in higher yields (on average 80 % higher) relative to conventional production systems. They assume that external inputs often are not available to farmers in developing countries, that the use of mineral fertilizers on grounds with low retention of nutrients reduces yields, and that high-yielding varieties are not appropriate for sites with suboptimal conditions.

Organic farming is regarded as site-specific and sustainable because of its circular flow of inputs. As demand for organic products is higher than supply in Germany, there is upward pressure on prices and more and more organic products are being imported. Thus growing organic foods for export could well be an option for small-scale producers, as noted by an evaluation of Church Development Service (Evangelischer Entwicklungsdienst) and Bread for the World (Brot für die Welt) (2011). However, markets in this segment are developing nearly along the same lines as conventional markets, resulting in unfair competition between producers within the EU and those abroad.

Many well-informed consumers are appalled at the way German farming systems operate. Some agriculture in Europe may never be economical without subsidies. Public money should not be spent for preserving this kind of agriculture. Subsidies should be spent for a system of agricultural production that is fit and viable for the future, in a manner that is adapted to the soils and living conditions of animals and people. There is an urgent need for change to protect public goods.

C. Food control

The outbreak of the BSE crisis some 10 years ago created a massive crisis of confidence, which prompted the Commission of the European Communities (2000) to undertake a study that resulted in the so-called White Paper on Food Safety.[71] It was and still is the crucial strategic document for food safety in the EU. We at the Federation of German Consumer Organisations wondered whether that strategy has been successful. Is the principle of traceability fully operational so that we become aware of existing risks as early as possible? Do only safe globally traded goods reach our plates? Is the precautionary principle of the EU regulation on food safety being implemented?[72] And why do consumers still have distrust in the precautionary principle as applied?

According to a Eurobarometer survey on risk perception in the EU (European Commission, 2010), 11 per cent of those surveyed believed that the probability of eating foods which have negative effects on health was very high, and 37 per cent believed that it was fairly probable. There were similar data for Germany. Furthermore, many consumers are still asking for a systemic change in agricultural production methods. The Eurobarometer survey also reveals that people are increasingly worried about chemical residues from pesticides in fruit, vegetable and cereals, with an average of 31 per cent of respondents in the EU expressing such concerns, 91 per cent in Greece, 80 per cent in France and 75 per cent in Germany. Concerning the use of antibiotics or hormones in meat, an average of 30 per cent of respondents throughout Europe reported being very worried, 99 per cent in Cyprus and 63 per cent in the Netherlands. The EU average for respondents expressing concern about the cloning of animals for food products was 30 per cent, and 29 per cent were concerned about pollutants such as mercury in fish and dioxins in pork. Forty-two per cent of those surveyed did not believe that the public authorities in the EU viewed the health of citizens as more important than the profits of producers, and more than 81 per cent felt that public authorities should do more to ensure that food is healthy and inform people about healthy diets and lifestyles.

The White Paper on Food Safety makes manufacturers, importers, carriers and retailers responsible for the food safety of products. They have to ensure and document the safety of their goods. Additionally, a system of food controls is being implemented through official monitoring of food and veterinary matters. The competent authorities try to detect problems with food safety as early as possible and take appropriate measures. The Federal Office of Consumer and Food Safety (BVL) in Germany tried to develop emerging risk identification systems. But it is not clear how effective these can be. One of the obligations of businesses is to trace the origin of products when they are observed to pose a health hazard and help remove those products from the market as quickly as possible. The idea is to trace the complete food and feed production chain, from the source of production to the retailer.

D. Limits of food safety

Food safety is closely linked to questions of animal and plant health and animal welfare. In the EU, the Food and Veterinary Office (FVO) is responsible for verifying compliance with EU standards concerning these three areas. According to SANCO (2010), it carries out 250 inspections annually, of which one third are undertaken in developing countries. The FVO looks at the legal framework and whether regulatory measures are in place to ensure that producers apply the standards stipulated and enforce them. It also checks the work of the competent authorities and their surveillance and control measures (e.g. whether they have adequate facilities, such as laboratories, independence of work, information policy, certification practices, control systems and records). It also looks at production establishments, handling and storage sites and laboratories.

According to SANCO we know from the work of FVO, that the main food safety problems concern the following areas: the legal and administrative infrastructure, a lack of understanding of control system requirements (especially of EU requirements), inadequate control and enforcement mechanisms, and lack of, or inadequate, facilities for control and certification purposes (SANCO, 2010). Although there is no doubt that there is greater cooperation between the competent outhorities in the different countries in technical assistance and capacity-building with regard to European food safety, there are problems, such as inadequate infrastructure in exporting countries. In addition to that, some official food and feed authorities reflect more the interests of the business community than consumer interests. Food safety is also in danger because of a growing amount of unsafe products (such as dietary supplements) offered via the Internet. The growing market for enriched food (e.g. containing vitamins and minerals) presents food safety risks because of the risk of overconsumption of those additives. Another problem arises from pharmaceutically active substances not approved in Europe and sold as food on the Internet.

Imported products are still largely a "black box" in the sense that laboratories in Europe are only able to find residues they are looking for. Without information about the agricultural production methods and related inputs (for instance the use of veterinary drugs in animal husbandry) those laboratories are unlikely to find the residues. The control system in the EU needs to be continuously improved. In contrast with the industry, the authorities are not sufficiently interconnected and are always one step behind new technologies, new active pharmaceutical ingredients and new products that pose new risks. From notifications about unsafe foods in the EU's Rapid Alert System of Food and Feed (RASFF), it is evident that food and feed products imported into the EU are not automatically safe. Pathogenic micro-organisms, allergens, genetically modified organisms (GMOs), mycotoxins and residues in food released from packaging are the principal causes of unsafe foods. Food safety and food quality require global efforts by the industry and the official regulatory and controlling authorities. Five per cent of foodstuff consumed in the EU originates from third countries (SANCO, 2010). The question therefore arises as to how a global alert system could be organized and whether the European system is suitable for other countries, particularly developing countries.

John Dalli, the former Commissioner for Health and Consumer Policy (2010: 3), noted that "more than sixty countries outside the EU were connected to the RASFF Window, a new online platform, which allow[s] them to download RASFF notifications that might concern them. The Commission would continue its efforts to support those countries in setting up their alert systems, through the *Better Training for Safer Food* programme, to enable them to tackle food safety incidents that gradually become more global in nature." Cooperation between countries and between public health and food safety authorities is essential to manage hazards in food. This has been starkly illustrated by the case of EHEC O104: H4, a deadly E.coli bacterium strain caused by contaminated sprouts that killed at least 45 people and caused a major food crisis in Germany in 2011.

E. International food standards

Collective standards, such as GlobalGAP, Safe Quality Food, Quality and Safety or Label Rouge (for more information, see Guenther and Will, 2007), are increasingly serving as quality assurance schemes for corporations involved in the global food chain. They serve as a guarantee for stable food quality in a world of horizontally and vertically integrated producers.

As consumer organizations show in recent market surveys, processed food is considerably more expensive and very often enriched with unnecessary food additives that pose the risk of overdosage. Many of these processed food products also contain aromas, additives for conservation and/or taste-enhancing substances aimed at keeping them fresh, appealing and non-perishable while being shipped worldwide. In this respect, products of big companies everywhere in the world adhere to the same standards. However, the way food standards are set and who sets them is not transparent to consumers. Indeed, many consumers realize that their understanding of food safety and their ethical concerns are not automatically being considered in the international market, and that standards often work against consumer interests (Mühleib, 2010). For instance, there are conflicts between consumers in the EU and exporting business in the United States over GMOs, chlorinated poultry and hormones in meat and dairy production. The majority of European consumers are wary of products of cloned animals or genetically modified fish, but commercial pressure groups often try to influence public debate and sentiment on this issue.

According to Tanzmann (2011), the Church Development Service and Bread for the World want food standards to be negotiated at the multinational level. But the solution is not that standards should be lowered to a level that would enable compliance by all producers. Consumers' desire for food safety varies depending on the cultural background of the country where products are consumed. If the Federal Institute for Risk Assessment (BfR) in Germany, for instance, defines the limit values for residues, these refer to the minimal quality producers have to comply with. This is why there will always be a conflict between the interests of consumers in developed countries and producers in developing countries. Horton and Wright (2008) have shown that developing countries would stand to benefit if the United States and Europe adopted the same standards. But from the perspective of European consumers, harmonization of United States and European standards would, in most instances, have negative effects, as illustrated by the example of chlorinated poultry.

F. Equivalence of production and of quality management instruments

Consumers may discriminate against products from developing countries if the standards of those countries are not accepted as equivalent to European standards. Equivalence in this context does not mean that products should be produced using the same processes, but in a comparable way. Products, processing techniques and ways of conforming with food safety requirements may differ.

Although there is a comprehensive set of control instruments for food safety, it will not be sufficient to safeguard food safety for all internationally traded products. In sum, a systematic approach towards the control system is missing. Instead of harmonizing the elements of standards, their number is still growing. Many requirements and standards of food safety have been introduced by multinational agribusiness to their advantage, but rarely in cooperation with the farmers who have to manage the requirements. Equivalence of production and of quality management instruments should be judged by bodies that are independent of industry and in accordance with consumer demand.

G. Conclusions

Increasing globalization has accelerated the industrialization of agricultural practices and cost pressures among producers. This has led to larger scales of production of homogeneous agricultural goods in a decreasing number of production units, with several unresolved food-safety risks that are difficult to manage.

Many food safety issues are related to diseases of plants and animals and to the use of external inputs such as agrochemicals and antibiotics. Intensified agricultural production has a negative impact on public health and well-being, and that process seems to have reached its limits. Because of the pressures of competition, producers are constantly seeking to reduce their production costs. This means that in the absence of effective regulation, production standards will follow a "race to the bottom" with the result that in terms of environmental, social and ethical criteria the cheapest and lowest standards might be applied.

Although there are comprehensive control mechanisms to ensure food safety,[73] they are insufficient to guarantee food safety for all internationally traded products. What is lacking is a proactive, preventive approach. Instead of different safety standards and requirements being harmonized, the number of divergent requirements is still growing. Many standards and requirements have been introduced to the advantage of multinational agribusinesses, but often not in cooperation with the farmers who have to conform with those requirements.

Controls to safeguard European food safety have certain limitations. The current approaches to assuring food safety are complicated and expensive, especially for small-scale producers, and in the end producers and consumers pay the additional costs. The notion that more controls are sufficient to guarantee adequate food safety has proved wrong: additional controls have not been able to halt or reverse the trend of increasing contaminants in food products and greater environmental pollution. A systemic change towards low-risk, sustainable production techniques will ease the problems of food safety related to the production and processing of food. It may also improve the level of trust of consumers in agricultural products.

The food industry, should help improve the basis for healthy nutrition by ensuring the quality of raw materials and inputs in processed food. The industry should also ensure that production is environmentally friendly and applied to the locations where production takes place.

Governments need to cooperate nationally and internationally to incorporate the prevention of risk factors into other policy-making areas. Measures relating to areas such as food security and food safety, food production, agriculture, health, environment, trade, taxation, education and urban development need to be coherent and should adhere to the precautionary principle.

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Notes

1 Food security is generally defined as consisting of four pillars: (i) availability (i.e. the supply side of food security, resulting from production, stocks and trade); (ii) access (influenced by income, markets and prices); (iii) utilization (related to diets, food preparation and conservation practices); and (iv) stability (i.e. periodic shortfalls, fluctuation of supply). For more information, see *inter alia* FAO (2012a).

2 On the basis of current trends, carbon emissions will keep growing by about 3 per cent per annum and at this rate will reach the remaining emission limit of 565 gigatons to keep global warming below 2 degrees within no more than 16 years. www.rollingstone.com/politics/news/global-warmings-terrifying-new-math-20120719.

3 For more information, see ibid.

4 According to Fatih Birol, the IEA's chief economist, the current trends are perfectly in line with a temperature increase of about 6 degrees later this century. Ibid.

5 Global cereal production volume grew by 17 per cent and cereal yields increased by 6 per cent in the period 1990/1991 to 2005/2006 (author's calculation, based on FAOSTAT).

6 For more information, see Keane et al. (2009).

7 It is often overlooked that productivity of outdoor workers is bound to considerably decline because of global warming. In India, for instance, it is estimated that productivity of outdoor workers has already dropped by 10 per cent since the early 1980s and that another 2 degrees temperature increase might result in an additional reduction of 20 per cent (Rundgren, 2012).

8 For an overview of recent significant climate anomalies, see Tirado and Cotter (2010: 4–5).

9 The recent catastrophic floods in Pakistan and the massive forest and peat-soil fires in Russia are but two illustrative examples of the impact that can be expected. As the case of Pakistan demonstrates, both the country and the international community are poorly prepared to effectively cope with such extremes. Apart from the dire consequences for future agricultural production, there is also the risk of serious destabilization of society and the political system. Estimates of the flood-caused economic damage are as high as 20 per cent of Pakistan's GDP.

10 It is estimated that elevated atmospheric CO_2 concentration alone may increase crop yields by some 10–15 per cent. Crops that tend to benefit from the effect of carbon fertilization include rice, wheat, soybeans, fine grains, legumes, and most trees. Benefits for other crops, including maize, millet, sorghum and sugarcane are more limited. However, these estimates need to be considered with utmost care, as other changes such as distribution of precipitation, elevation of atmospheric O_3 concentration, enhanced demand for nitrogen, and increases in temperature can make the yield increases highly uncertain (Smith et al., 2007a: 25). See also the comment of Högy and Fangmeier in this Chapter.

11 The quality of food is determined by three elements: (i) calories (i.e. the energy content); (ii) proteins; and (iii) micro-nutrients.

12 Fruit and vegetables are very valuable for dealing with micronutrient deficiencies (the value of global trade in vegetables, for instance, exceeds that of cereals). Yet, there is insufficient knowledge and research on the effects of climate change on fruit and vegetable yields and quality (FAO, 2012a).

13 It is estimated that currently about 30-40 per cent of the potential global crop yield is destroyed by pathogens and pests (Oerke, 2006).

14 Resilience is the capacity to absorb or cope with shocks and stresses. Adaptive capacity is defined by overlapping resources and abilities that can be employed to respond to and create changes (Naerstad, 2011: part ii, p. 33).

15 What makes the situation in Africa, South Asia and Central America particularly precarious is the fact that the population of Africa is projected to double in the period 2010-2050; that of South Asia and Central America to increase by more or somewhat less than 40 per cent (UN/DESA, 2010).

16 Climate change is already clearly visible. According to the World Meteorological Organization, the decade from 2001 to 2010 had a global temperature that was 0.46^{0}C above the 1961-1990 average; the highest value ever recorded for a 10-year period. Warming was especially strong in Africa, parts of Asia and the Arctic, Central Asia and Greenland/Arctic Canada (WMO, 2010). According to the global Climate Risk Index (CRI), developed by Germanwatch and Munich Re NatCatSERVICE, the 10 most climate-risk-exposed countries in the period 1990-2009 were: Bangladesh, Myanmar, Honduras, Nicaragua, Viet Nam, Haiti, Philippines, Dominican Republic, Mongolia, and Tajikistan (the CRI reflects both relative and absolute climate impact per country: for more info see www.germanwatch.org/klima/cri.htm).

17 It is estimated that already by 2025 continuing population growth and current agricultural practices will jack up the number of countries that suffer from an acute scarcity of either good cropland or fresh water from 21 at the moment to some 57, with a total population of 2 billion. Water scarcity may be one of the most powerful crop yield reducers in the coming decades. (Giovannucci et al., 2012: 22).

18 The economic significance of agriculture in developing countries is usually under-estimated when limiting it to agriculture's contribution to GDP, because large parts of agricultural production are informal and not part of the monetary economy.

19 It is also worth noting that, for the first time in history, there are as many overweight people as undernourished. The consequences of the emerging dietary habits are on a disastrous trajectory for human and ecosystem health. Therefore, one also needs to target the quality of nutrition rather than simply "more production" (Giovannucci et al., 2012: iv and vi).

20 According to FAO, Sub-Saharan Africa has the highest share of undernourished people, some 30 per cent in 2010, whereas the Asia Pacific region has the most undernourished people (about 578 million). Two-thirds of the world's undernourished live in just 7 countries: Bangladesh, China, the Democratic Republic of Congo, Ethiopia, India, Indonesia and Pakistan (cited in Giovannucci et al., 2012: 6).

21 As highlighted by De Schutter and Vanloqueren (2011:38), "large, mechanized, mono-cropping operations are more competitive than small farms …, but competitiveness and productivity are different things. Big farms outperform small farms according to only one measure of economic efficiency: productivity per unit of labour". According to Tscharntke et al. (2012: 54), "it is well established that small and diversified farms rather than large monocultures show greater productivity per area; a phenomenon referred to as the 'paradox of the scale' or the 'inverse farm size-productivity relationship'."

22 See also IAASTD (2009a).

23 As emphasized by Naerstad (2011: part II, p. 37), "soil organic matter as humus can only be produced by the diversity of life that exists in soils - it cannot be human-made. When the soil organic matter recycling and fertility service is impaired, all life on earth is threatened, as all life is either directly or indirectly reliant on plants and their products, including the supply of food, energy, nutrients, construction materials and genetic resources".

24 Increasing soil organic matter by good management practices is generally synergistic because it captures atmospheric CO_2, increases soil fertility and improves the soil structure for more resilience and better adaptation to climate change (FAO, 2012a).

25 This section draws on findings of Murphy and Wise (2012).

26 One response was the (voluntary) Principles for Responsible Agricultural Investment (PRAI), developed by the secretariats (not the member countries) of the World Bank, FAO and UNCTAD, which have been widely criticized as far too weak (Murphy and Wise, 2011: 31). In May 2012, the FAO's Committee on World Food Security (CFS) endorsed The Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security, which outline principles and practices that governments can refer to when making laws and administering land, fisheries and forests rights. The guidelines are based on an inclusive consultation process started by FAO in 2009 and then finalized through CFS-led intergovernmental negotiations that included participation of government officials, civil society organizations, private sector representatives, international organizations and academics. The aim of the guidelines is to promote food security and sustainable development by improving secure access to land, fisheries and forests and protecting the rights of millions of often very poor people. While the guidelines acknowledge that responsible investments by the public and private sectors are essential for improving food security, they also recommend that safeguards be put in place to protect tenure rights of local people from risks that could arise from large-scale land acquisitions, and also to protect human rights, livelihoods, food security and the environment (for more information, see http://www.fao.org/news/story/en/item/142587/icode). As the guidelines were only adopted in mid-2012, it is as yet too early to judge whether they will have a real impact on effectively governing existing and new foreign land acquisitions.

27 For an elaborate discussion, see Naerstad (2011).

28 For a recent in-depth review, see: German National Academy of Sciences Leopoldina (2012).

29 For an elaborate discussion, see: FAO (2011a).

30 The IPCC (2007a) suggests 10–12 per cent, the OECD suggests 14 per cent (Legg and Huang, 2010), and the World Resources Institute (WRI, undated) suggests 14.9 per cent.

31 Figures used for the calculations were: (a) an average loss of 4.5-–6 kg of SOM/m^2 of arable land and 2–3 kg of

SOM/m[2] of agricultural land under prairies and not cultivated; (b) an average soil depth of 30 cm, with an average soil density of 1 gr/cm[3]; (c) 5,000 million ha of agricultural land worldwide and 1,800 million ha of arable land (FAOSTAT, 2002-2004); and (d) a ratio of 1.46 kg of CO_2 for each kg of destroyed SOM .

32 This conclusion is based on the assumption that organic matter would be incorporated at a global annual average rate of 3.5 to 5 tons per hectare of agricultural land. For more detailed calculations, see GRAIN, 2009, table 2.

33 Agroecological research combines modern science with local knowledge. In Central America, for instance, the coffee groves that grow under high canopy trees were improved by identifying the optimal shade conditions for minimizing the entire pest complex and maximizing the beneficial microflora and fauna, which improved yield and coffee quality. Such good practices are developed through a trial-and-error process by coffee-growers, but identifying conditions for success in order to promote their dissemination may benefit from the knowledge of experts (Staver et al., 2001).

34 The 79 per cent figure relates to the 360 reliable-yield comparisons from 198 projects, but the results were wide ranging, with 25 per cent of the projects reporting a 100 per cent increase or more.

35 However, it should be pointed out that not all these projects comply fully with the principles of agroecology.

36 Research on agroforestry in Zambia does not support “the popular notion that agroforestry practices are more labour intensive” (Ajayi et al., 2009: 279).

37 See: www.climatefundsupdate.org.

38 According to the IPCC, an atmospheric CO_2 concentration of 550 ppm will lead to a 3°C rise in global average temperatures.

39 C_3 is a metabolic pathway for carbon fixation in photosynthesis, converting CO_2 and ribulose bisphosphate (RuBP) into two 3-carbon molecules of 3-phosphoglycerate (3-PGA).

40 C_4 is a metabolic pathway for carbon fixation in photosynthesis, which fixes CO_2 to phosphoenol pyruvate (PEP) and converts it into the 4-carbon intermediate malate.

41 The whole paper can be downloaded at ftp://ftp.fao.org/docrep/fao/011/ak355e/ak355e00.pdf.

42 Statements by Feed the Future officials are revealing: they refer to the “discovery and delivery” of “breakthrough” technologies, frequently mentioning biotechnology rather than agroecological approaches. See statements by USDA Secretary Tom Vilsack at:http://www.america.gov/st/develop-english/2010/May/20100521164320akllennoccm1.705134e-02.html; USAID Director Rajiv Shah at: http://www.usaid.gov/press/releases/2010/pr100616.html; and Monsanto Corporation at: http://www.america.gov/st/develop-english/2010/July/20100722113758cpataruk0.2630579.html&distid=ucs. See also Gates Foundation at: http://www.gatesfoundation.org/agriculturaldevelopment/Pages/why-we-fund-research-in-crop-biotechnology.aspx.

43 This USAID programme partners with biotechnology industry leaders such as Monsanto, Mayco and Bayer. For details, see: http://www.absp2.cornell.edu/.

44 A toe is a common unit of energy, which expresses the amount of energy released when a ton of oil is burnt (1 toe = 42 GJ = 11 MWh = 10 Gcal).

45 Water pumping consumes considerable energy.

46 Soybeans can be grown without nitrogen fertilizers as they have natural nitrogen fixation properties, which is the main reason for their lower energy demand.

47 While there were also other factors driving the increase in food prices, such as the diversion of some crops for the production of biofuels, increased meat consumption and speculation, the higher oil price was doubtless a major driver.

48 The introduction of energy-saving stoves or the use of other fuels that are easier to regulate should be a priority, not only for the conservation of forests and saving of energy, but also because the traditional stoves emit considerable indoor soot and smoke, which are a health hazard and one of the biggest killers. Between 1.5 million (WHO, 2006) and 4 million (Pimentel et al., 1998) people die from these emissions every year.

49 Assuming that the farmers can save their entire surplus, which is highly unlikely.

50 See: http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/.

51 See: Off-grid systems, at: www.energy-solutions.co.uk/off-grid/.

52 See Lighting Africa, Catalyzing markets for modern lighting, at: www.lightingafrica.org/.

53 See: http://earthobservatory.nasa.gov/Features/Dust/.

54 This paper draws heavily from a 2010 article by the authors entitled, Competition for Water for the Food System, published in *Philosophical Transactions of the Royal Society: Biological Sciences*, 365(1554): 2765–3097.

55 A thorough discussion of these and other solutions is provided in several comprehensive reports (e.g. IWMI, 2007).

56 The relationship between population, water and food production has been explored in depth by a number of authors (see, for example, Gleick, 1996; Pimentel et al., 1997; Postel, 1998; Vörösmarty et al., 2000; Tilman et al., 2001; and IWMI, 2007).

57 Note that this paper does not consider threats to agricultural withdrawals from groundwater resources that are not directly linked to surface water systems, as these resources are unlikely to serve as a viable substitute for surface water in future years. In many regions of the world, groundwater reserves have declined to the point where well yields have fallen dramatically, land has subsided, and aquifer salinization has occurred (Konikow and Kendy, 2005). As the global demand for groundwater continues to increase, groundwater tables and well yields will decline more rapidly, reducing surface water runoff and forcing those that rely on groundwater resources to seek new sources. Both will have negative effects on the availability of water for agriculture.

58 In this paper, our focal "geopolitical regions" are Europe, Africa, North America, Asia, Latin America and the Caribbean, and Oceania. Within Europe, we also focus on the European Union, north-western Europe, the United Kingdom, and the former Soviet Union. Sub-Saharan Africa and the Nile River basin are reported for Africa, and in Asia, we report findings for China and India. Finally, we identify impacts on Brazil.

59 Following Winter et al. (1998), we assume that regional groundwater withdrawals deplete river basin runoff and therefore implicitly consider subsurface water in our modelling exercise. It must be noted that this analysis may underestimate threats to agriculture, for two reasons: (i) we make these comparisons relative to current agricultural demands rather than the expected higher demands of 2050; and (ii) we do not consider the effects of drought or increased extreme events. On the other hand, the analysis may overestimate threats because we model withdrawals rather than consumptive use and thus do not account for reuse of return flows.

60 Measurements were taken in 10 plots of passion fruit in mixed cropping systems in each of two different areas of the Central and Western Provinces of Kenya.

61 For further information, see: www.4c-coffeeassociation.org/our-services/work-on-climate-change.html.

62 See: www.growingforthefuture.com/content/Cool+Farm+Tool.

63 For a more detailed discussion of the development of food supply chains in low-income countries and emerging economies, see Parfitt, Barthel and Macnaughton, 2010.

64 See: www.wfp.org/purchase-progress.

65 In some EU countries (e.g. Germany), absolute expenditure on food has remained constant since the 1960s.

66 See, for example: www.neweconomics.org/publications/inconvenient-sandwich.

67 Further information about the Platform's views in English, see: www.die-bessere-agrarpolitik.de/English-documents.1024.0.html.

68 See also: www.efsa.europa.eu/en/topics/topic/amr.htm?wtrl=01.

69 The SANCO study cited Anderson (2008).

70 See also, Stockholm Resilience Centre, Stockholm University, Tipping towards the unknown, at: www.stockholmresilience.org/planetary-boundaries.

71 Regulation (EC) No 178/2002, laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety, http://ec.europa.eu/dgs/health_consumer/library/pub/pub06_en.pdf.

72 Article 7 of Regulation EC 178/2002 "formally establishes the precautionary Principle as an option open to risk managers when decisions have to be made to protect health but scientific information concerning the risk is inconclusive or incomplete in some way.". See: http://ec.europa.eu/food/food/foodlaw/precautionary/index_en.htm, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2000:0001:FIN:EN:PDF.

73 For more details, see: Guenther and Will, 2007.