

Agricultural Sustainability

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Executive summary

Globally, agriculture has performed remarkably well over the last 50 years, by keeping pace with rapid population growth and delivering food at progressively lower prices. But this success has been at the expense of the natural resource base, through overuse of natural resources as inputs or through their use as a sink for pollution.

The evolution of thinking on sustainability is reviewed. Current understanding maintains that agriculture is sustainable when current and future food demands can be met without unnecessarily compromising economic, ecological, and social/political needs. This moves beyond interpretations of sustainability based solely on ecological factors and farming systems. Key features of agricultural sustainability include an acceptance of the fact that agricultural strategies should be based on more than simple productivity criteria, that externalities are of great importance, and that intra- and inter-generational equity are key parameters in assessing agricultural change.

The ecological impacts of agriculture include land degradation, limits to water availability, loss of biodiversity, declining agricultural genetic diversity and contributions to climate change. Such problems are referred to in the paper as *negative externalities*: these are recognised to be often neglected, occurring with a time lag, affecting groups with little voice in decision-making, and difficulty to track to source. While agriculture also has positive effects on the environment, these are outweighed by the overall impacts.

In the context of sustainability, two key questions are addressed. Firstly, whether agriculture will be able to meet future global food demands without adversely affecting the resource base. Secondly, what is the optimum approach to enable agriculture to both provide sufficient food and also act as an engine of pro-poor growth despite resource constraints.

Overall, global agricultural production is projected to grow in line with demand, provided that the necessary national and international policies promoting agriculture are in place. But this global picture masks regional inequity. In developing countries overall, cereal production is not expected to keep pace with growing demand associated with both population growth and changing patterns of consumption, such as increasing demand for livestock products.

For agricultural growth to occur at the rate required to meet future demand, a series of factors will need to be in place. These include availability of land, better use of water resources, capability to accommodate climate change and management of genetic resources. Meeting current and future food requirements will require rapid increases in

productivity to avoid an undesirable expansion onto fragile and marginal lands. However, production increases need to happen without further damage to the environment.

For this to happen, principles of sustainability must be a core part of agricultural policies, to provide incentives and enabling conditions for sustainable resource use. Such principles should also be reflected in macro policies that can potentially influence different groups of poor people, the resources they use and their scope for positive adaptation.

In practice, progress on the ground still remains largely despite of, rather than because of, explicit policy support for sustainable agriculture. Whilst policy reforms are underway in many countries progress has tended to be piecemeal. Lack of significant progress in design and implementation of better policy is due in part to strongly divergent opinion on optimum approaches for agriculture.

While some believe that ecological limits on growth have been reached, others believe that market forces and biotechnology will enable supply to meet demand – in some scenarios with modernised agriculture taking over from small scale farming. Differences of opinion also exist over the relative sustainability of low versus high input systems, the role of biotechnology, and the productive capacity of organic systems.

Divergent opinions are frequently rooted in ideological stances. But the idea of agricultural sustainability does not mean ruling out any technologies or practices on ideological grounds. If a technology works to improve productivity for farmers, and reduces environmental impacts, then it is likely to be beneficial on sustainability grounds.

Accepting that different solutions will suit different contexts, empirical evidence does suggest certain key principles. Agricultural sustainability requires a focus on both genotype improvements through the full range of modern biological approaches, as well as improved understanding of the benefits of ecological and agronomic management and manipulation. Additionally, agriculture is most sustainable when better use is made of existing resources and technologies through 'sustainable intensification', rather than employing extensive approaches.

Policies, institutions and technologies need to increase synergies between poverty reduction, agricultural production and environmental sustainability. Better information is required to close knowledge gaps, including means of measurement and monitoring. To maximize agriculture's efficiency and sustainability, public policy should seek to internalize all costs and benefits in the prices of production inputs, such as improving pricing mechanisms for irrigation water, facilitating land market development, and eliminating distorting taxes and subsidies on agrochemical inputs, including fertilizers. Secure property rights and other policies offering farmers incentives for investing in resource management, as well as access to yield-increasing and resource-conserving technologies are critical. Specific policy priorities for agricultural sustainability are presented.

1. Introduction

Globally agriculture has performed remarkably well over the past half century. Since the 1960s the world food system has responded to a doubling of the world population from three to six billion, providing more food per capita at progressively lower prices. Within the same time frame, world per capita agricultural production has increased by 25%. However, aggregate figures mask significant regional variations. In Asia and Latin America, per capita food production has increased by 76% and 28%, respectively. In contrast, Africa has fared badly, with food production at 10% less per person today than in 1960.

This relative success in increasing agricultural productivity has, however, brought with it substantial environmental challenges. Agriculture is the most important user of environmental resources, including water, forests, pastures and nutrients, and its sustainability depends upon their availability (DFID, 2002). Five key environmental challenges can be identified that potentially threaten the future viability of agricultural systems, particularly at regional and local levels:

1. Land degradation
2. Limits to water availability
3. Loss of biodiversity
4. Declining agricultural genetic diversity
5. Climate change.

So, the challenges to be faced are enormous. This paper poses two key questions on the relationships between agricultural sustainability, food security and pro-poor growth.

First, with global food demand projected to double over the next 50 years (Tilman et al., 2002) and more than 800 million people already facing hunger and lacking adequate access to food there are huge challenges for the sustainability of food production and the environment. So, looking to the future, will it be possible to sustain and accelerate current rates of agricultural output without negatively impacting the resource base?

Second, agriculture remains the principal livelihood of poor people in developing countries, and particularly the rural poor, and is widely considered to be the major "engine" of economic growth in the majority of developing countries. Given the past contribution of agriculture to poverty reduction and economic growth, do improvements in agriculture have the potential to stimulate further pro-poor growth in the face of existing resource constraints?

2. The current evidence: what do we know?

2.1 The evolution of thinking on sustainability

In 1798 Thomas Malthus first put forth the observation that, if unrestrained, population growth would eventually overtake the ability to produce food leading to starvation and war (Malthus, 1798). But, since the mid-20th century, rising food demand has led to improved agricultural technologies so that the so-called Malthusian trap has been avoided, at least for the time being.

However, environmental concerns about limits to growth began to emerge in the 1950s and 1960s, stimulating different debates about future scenarios. In the 1960s, concerns were voiced about the environmental risks caused by agriculture, driven in particular by Rachel Carson's book *Silent Spring* (Carson, 1963). In the 1970s, the Club of Rome's controversial report on "Limits to Growth" (Meadows et al, 1972) identified the economic problems that societies would face when environmental resources were overused, depleted or harmed, and pointed to the need for different types of policies to generate sustainable economic growth. In the 1980s, the World Commission on Environment and Development, chaired by Gro Harlem Brundtland, published *Our Common Future*, the first serious attempt to link poverty alleviation to natural resource management and the state of the environment (World Commission on Environment and Development, 1987). Sustainable development was defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". The concept implied both limits to growth and the idea of different patterns of growth. In 1992, the UN Conference on Environment and Development held in Rio de Janeiro, raised the international profile of threats to agricultural sustainability.

2.2 The concept of agricultural sustainability – three dimensions

Many different terms have been used to imply greater sustainability in agricultural systems than in prevailing systems (both pre-industrial and industrialised). Each emphasises different values, priorities and practices (Pretty, 1995, 2002).

One interpretation of *sustainable agriculture* focuses on types of technology in particular settings, especially strategies that reduce reliance on non-renewable or environmentally harmful inputs. These include ecoagriculture, permaculture, organic, ecological, low-input, biodynamic, environmentally-sensitive, community-based, farm-fresh and extensive strategies. There is intense debate, however, about whether agricultural systems using some of these terms actually qualify as "sustainable".

A second and broader interpretation – which is used in this paper – focuses more on the concept of *agricultural sustainability*, and goes beyond particular farming systems. Sustainability in agricultural systems is viewed in terms of resilience (the capacity of

systems to buffer shocks and stresses) and persistence (the capacity of systems to carry on). It implies the capacity to adapt and change as external and internal conditions change. The conceptual parameters have broadened from an initial focus on environmental aspects to include first economic and then wider social and political dimensions (Cernea, 1991; DFID, 2002):

- *Ecological* – the core concerns are to reduce negative environmental and health externalities, to enhance and use local ecosystem resources, and preserve biodiversity. More recent concerns include broader recognition for positive environmental externalities from agriculture.
- *Economic* – economic perspectives on agricultural sustainability seek to assign value to ecological assets, and also to include a longer time frame in economic analysis. They also highlight subsidies that promote the depletion of resources or unfair competition with other production systems.
- *Social and political* – there are many concerns about the equity of technological change. At the local level, agricultural sustainability is associated with farmer participation, group action and promotion of local institutions, culture and farming communities. At the higher level, the concern is for enabling policies that target poverty reduction.

The relative values that people place on different trade-offs between these three dimensions vary over time and place. Achieving a balance between them is one of the greatest challenges to operationalising the concept of agricultural sustainability. Environmental and social sustainability of productive resources depend in part on economic profitability that must provide for reinvestment in the maintenance of these resources (including the natural environment) and on a satisfactory standard of living for owners and employees involved in the production process. In turn, economic sustainability is dependent on a productive workforce and productive natural resources.

Key features of agricultural sustainability include an acceptance of the fact that agricultural strategies should be based on more than simple productivity criteria, that externalities are of great importance, and that intra- and inter-generational equity are key parameters in assessing agricultural change (DFID, 2002).

2.3 Agricultural growth and resource implications

In most developing countries, agricultural and industrial revolutions did not begin until well into the twentieth century. In the last half century, rapid technological progress in the production of the major staple foods across much of the developing world has brought impressive results.

Since the 1960s, land in agricultural use (arable land and land under permanent grass and tree crops) in the world has increased by 12% to about 1.5 billion ha (FAO, 2004). This amounts to 11% of the Earth's surface.

Over the past three decades, the area of land under irrigation has doubled and fertiliser use has increased 18-fold, resulting in a 20% increase in per capita food production (Conway, 1997). Between 1950 and 2000, world production of grain nearly tripled, and average grain yields have risen from the 1–2 to the 6–8 metric tonnes per hectare range (Ruttan, 2002). In the past four decades, total world food production grew by 145%. In Africa, it is up by 140%, in Latin America by almost 200%, and in Asia by a remarkable 280%. The greatest increases have been in China, with an extraordinary 5-fold increase, mostly occurring in the 1980s and 1990s (Pretty, 2003). But in recent years, growth in per capita food production has fallen back (Table 1).

Increased agricultural productivity and lower unit costs of food production have led to a sharp decline in real prices of cereals in world markets.

Table 1. Global production per person of grain, beef and mutton, and seafood (1950–2000)

Food	Growth period	Growth (%)	Decline period	Decline (%)
Grain	1950–84	+38	1984–2000	-11
Beef and mutton	1950–72	+44	1972–2000	-15
Seafood	1950–88	+112	1988–1998	-17

Source: FAOSTAT

The major ingredients for boosting crop yields through the Green Revolution were public investments in irrigation and roads, public research on high-yielding varieties and reliable supplies of fertilizers and pesticides. Most of the successful breakthroughs in productivity have, however, occurred in more favoured agroecological zones, such as India, and bypassed most of sub-Saharan Africa. Advances in animal production have come from genetic improvements and advances in animal nutrition.

All of this progress in agricultural productivity over recent decades has, however, been associated with costs to the environment in many parts of the world. Agriculture can negatively affect the environment through overuse of natural resources as inputs or through their use as a sink for pollution. Experience has shown that agriculture based on intensive use of inputs is prone to mismanagement that leads to environmental degradation, particularly where the system of incentives is inappropriate (Conway, 1997).

Agricultural intensification and extension have had negative impacts in four critical areas:

- *Land degradation.* Land degradation threatens the productivity of existing farmland and pastures. In many developing countries, agricultural land has soil that is low quality or prone to degradation. About 1.2 billion hectares (almost 11% of the Earth’s vegetated surface) has been degraded by human activity over the past 45 years. An estimated 5–12 million hectares are lost annually to severe degradation in

developing countries (Pretty and Koohafkan, 2002). Causes of degradation include water and wind erosion, contamination from industry and agriculture (including pesticides and fertilisers), and overuse of irrigation water causing salinisation. Soil degradation appears to be most extensive in Africa, where it affects 65% of the area used as cropland, compared with 51% in Latin America and 38% in Asia.

- *Water use and availability.* Irrigated agriculture is a major user of water and is crucial to the world's food supplies. One fifth of the world's cropland is irrigated, and this produces 40% of the world's food. In South Asia, over 80% of water resources are now used in agriculture. Despite great investment, water use efficiency in irrigation is generally very low and there are major concerns regarding resource depletion and persistent conflicts over water rights. Unsustainable exploitation of groundwater may lead to unforeseen problems such as arsenic contamination of drinking water. And, in large areas of India, water tables are already falling as demand is exceeding the sustainable yield of aquifers.
- *Loss of biodiversity.* Diverse agricultural systems and landscapes are resilient to shocks and stresses, with various plants, insects and animals helping to control pests and keep soils fertile. Many of the world's modern agricultural systems have become highly-simplified, and no longer making the best use of this "beneficial" biodiversity.
- *Declining genetic diversity in agriculture itself.* Only 150 plant species are cultivated for food worldwide, and only 3 (rice, wheat and maize) supply 60% of the world's calories. Genetic diversity in crops has been spiralling downwards – some 30,000 varieties of rice were grown in India fifty years ago; now only 10 varieties cover 75% of the all the rice-growing area. Reductions in agrobiodiversity increase disease and pest problems (Pretty, 2005).

Such effects are called *negative externalities* because they are usually non-market effects and therefore their costs are not included in market prices. As the polluter does not pay the full cost of their actions, so there are no rational incentives to reduce negative externalities (Pretty et al., 2000, 2003a; Waibel et al., 1999). Many agricultural systems also suffer by undermining key natural assets that they require to be successful.

Externalities in the agricultural sector have four features:

1. Costs are often neglected;
2. They often occur with a time lag;
3. They can affect groups whose interests are not well represented in political or decision-making processes; and
4. The identity of the source of the externality is not always known (Baumol and Oates, 1988).

BOX 1: Negative externalities of pesticides

There is little incentive for farmers to prevent pesticides escaping into water bodies as they transfer the full cost of cleaning up the environmental consequences to society at large. In the same vein, pesticide manufacturers do not pay the full cost of

their products, as they do not suffer from any adverse side effects that may occur. There is now emerging evidence to show the costs of some agricultural practices to environmental and human health (Crissman et al., 1998; Norse et al. 2001; Pingali and Roger, 1995). In China, for example, it is estimated that the externalities of pesticides used in rice systems cost \$1.4 billion per year through human health impacts and adverse effects on both on- and off-farm biodiversity.

Agriculture is also associated with *positive externalities*. Sustainable agriculture is multifunctional within landscapes and economies (Pretty, 2003). It not only produces food and other goods for farm families and markets, but it also contributes to a range of public goods, such as providing clean water, maintaining biodiversity, carbon sequestration in soils, groundwater recharge, and flood protection. Sustainable agricultural systems can have many positive side effects including helping to build natural capital, strengthen social capital and develop human capacities (Pretty, 2003; Ostrom, 1990).

2.4 Looking to the future...

Given the context of rapid agricultural growth and rising negative externalities in recent decades, what are the future projections for global food demand and environmental challenges related to agriculture?

Global food demand

Although global population growth slowed during the 1990s, the world's population is continuing to increase by 80 million a year due to population momentum. Over the next 50 years, the world's population is projected to increase by around 2.5-3 billion people (UNPF, 1999). Future global food and fibre demand is therefore expected to increase substantially as populations grow and average incomes and purchasing power rise.

In developing countries overall, cereal production is not expected to keep pace with demand. The net cereal deficits of developing countries, which amounted to 103 million tonnes or 9% of consumption in 1997–1999, could rise to 265 million tonnes (14% of consumption) by 2030 (FAO, 2004). One of the most important changes in the world food system will come from an increase in consumption of livestock products. Changes in income and lifestyle, in particular due to increasing urbanisation, lead to a radical shift in diet, often called the nutrition transition, with people consuming more meat and fewer traditional cereals and other foods. Because of this, meat demand is expected to rise rapidly, and this will change many farming systems. Livestock are important in mixed production systems, using foods and by-products that are not consumed by humans. But increasingly farmers are finding it easier to raise animals intensively, and feed them with cheap, though energy-inefficient, cereals and oils.

Currently, per capita annual food demand in industrialised countries is 550 kg of cereal and 78 kg of meat. By contrast, in developing countries it is only 260 kg of cereal and 30 kg of meat. These food consumption disparities between wealthy and poor people are expected to persist.

FAO contend that world agricultural production can grow in line with demand, provided that the necessary national and international policies promoting agriculture are in place. Global shortages are unlikely, but serious problems already exist at national and local levels and may worsen unless focused efforts are made (FAO, 2004).

Environmental and Resource Constraints

Given the likely projections for future global food demands, what do we know about the prospect of agricultural growth occurring at the level needed in the face of key environmental and resource challenges?

Land availability and degradation

In the foreseeable future, developing countries will need an estimated extra 102 million ha for crops, an overall increase of 12.5% (FAO, 2004). According to the FAO, this is more than half of the existing unused potential farmland in seven countries in Latin America and Sub-Saharan Africa, and other regions and countries are faced with a shortfall of land. Population growth and land fragmentation is a particular problem in countries like Bangladesh, where the average farm size has already fallen below 1 hectare. Yield losses due to land degradation pose problems in areas where soils are shallow, fields are steep, property rights are insecure, and farmers have limited access to inputs, information and markets.

Water use and availability

Water availability is central to agricultural development. With increasing urbanization and industrialization, agriculture faces increasing competition, and water availability is progressively constraining agriculture's contribution to growth and poverty reduction. Agricultural and non-agricultural users of water are increasingly in conflict. The role of irrigation is expected to increase still further, however, there are few remaining opportunities to expand irrigation cheaply. Water resources will be a major factor constraining expansion in South Asia and in the Near East and North Africa (FAO, 2004). These regions will need to achieve greater efficiency in water use. Improvements in the efficiency of agricultural water use can benefit both irrigated and rainfed farmers by enabling new or formerly-degraded lands to be farmed, and by increasing the cropping intensity on existing lands. In sub-Saharan Africa, for example, water harvesting is transforming barren lands into fertile farms with simple and cheap technologies.

Climate change

Scientists now generally agree that increased atmospheric concentrations of carbon dioxide and other greenhouse gases are causing significant warming of the Earth's atmosphere.

Gradual changes in temperature and the timing and levels of rainfall will reduce yields in some areas and enhance yields in others, depending on initial conditions. Global warming poses a huge threat to agriculture in the arid and semi-arid tropics. Likely impacts will be increased frequency and intensity of drought and new patterns of pests and diseases (DFID, 2002). Pressures on already scarce water resources will be increased in many poor countries. Although climate change may increase yields in some areas, cereal production in Africa is expected to decline by 2–3 by 2030 (FAO, 2002). Rising sea levels will threaten crop production in countries with large areas of low-lying land, such as Bangladesh and Egypt.

Biodiversity

Biodiversity will play a key role in future yield increases by providing the genetic resources needed to breed more productive varieties of plants, livestock and fish. Other characteristics, such as pest and drought resistance will also become increasingly important, especially if the climate changes as predicted. The CGIAR stores more than half a million samples of genetic materials of crops important to the poor (DFID, 2004).

Future options for agricultural growth

FAO highlight three main sources of growth in crop production:

1. Expanding the area of land used for growing crops
2. Increasing cropping intensities (multiple cropping and shorter fallow periods, often through irrigation)
3. Boosting yields.

Conventional wisdom holds that any attempt to increase the food supply to feed a growing world population will require a redoubling of efforts to modernize agriculture. However, whilst the Green Revolution was responsible for past increases in yields and cropping frequency, it is now much more difficult to tell a convincing story about the sources of increase in crop and animal production over the next half century (Ruttan, 2000). Some commentators suggest that we may be approaching the ceiling of what is possible for all three sources of growth in crop production in a number of countries and regions. Since the 1990s, the impressive global crop yield growth achieved earlier has decelerated sharply due to:

- diminishing returns to further input use;
- a slowdown in investment in infrastructure and research; and
- resource and environmental constraints.

Most of the land suitable for agriculture is already in production, so meeting current and future food requirements will require rapid increases in productivity to avoid an undesirable expansion onto fragile and marginal lands. However, production increases need to happen without further damage to the environment. This is where policies for agricultural sustainability come centre stage.

2.5 Policy and practice for agricultural sustainability

Researchers have identified eight key factors which appear to condition poverty–environment interactions and outcomes in relation to agriculture (McNeely and Scherr, 2001) which highlight key areas for policy response. These are:

1. The characteristics of the natural resource base and farming systems of the poor
2. Farmers’ awareness and assessment of the importance of environmental degradation
3. The availability of sustainable production technologies and their suitability for the poor
4. Farmers’ capacity to mobilize investment resources through their own assets and networks
5. Economic incentives for conservation management or investment
6. Security of tenure and rights of access to resources by the poor
7. The level of institutional capacity within communities to support adaptive responses by the poor
8. The degree of political inclusion of the rural poor in decisions affecting resource policies.

Macroeconomic and sectoral policies influence poverty–environment interactions by shifting these factors; thus macro policy typically has diverse impacts on different groups of poor people, the environments they use and their scope for positive adaptation. As an illustration of policy impacts, price pressure due to the expansion of supermarket buyer-driven chains can force farmers into unsustainable practices in order to sustain family income on a fixed land base.

BOX 2: Key policy issues affecting agricultural sustainability

- input subsidies encourage excessive use
- minimum support prices for cereals discourage diversification
- electricity or fuel subsidies encourage groundwater depletion
- subsidized milk/dairy imports discourage local production
- fuel or machinery subsidies discourage conservation tillage
- insecure property rights mean no incentive for long term investments.

There has clearly been increasing global recognition of the need for policies to support agricultural sustainability. The main agreement of the 1992 Earth Summit was Agenda 21, which set out priorities and practices in all economic and social sectors and how these should relate to the environment (see Box 3). The Agenda 21 chapter on “Promoting sustainable agriculture and rural development” is a call for governments to initiate or strengthen programmes of research, extension and land tenure primarily aimed at sustaining production through conservation and management of natural resources and germplasm.

BOX 3: Extract from Agenda 21 of the 1992 Earth Summit

"Major adjustments are needed in agricultural, environmental and macroeconomic policy, at both national and international levels, in developed as well as developing countries, to create the conditions for sustainable agriculture and rural development. The major objective of sustainable agriculture and rural development is to increase food production in a sustainable way and enhance food security. This will involve education initiatives, utilization of economic incentives and the development of appropriate and new technologies, thus ensuring stable supplies of nutritionally adequate food, access to those supplies by vulnerable groups, and production for markets; employment and income generation to alleviate poverty; and natural resource management and environmental protection.

Source: United Nations (1992)

However, progress has been limited, as Agenda 21 was not a binding treaty on national governments (Pretty and Koohafkan, 2002). However, the "Rio Summit" was followed by several important actions that came to affect agriculture:

- the signing of the Convention on Biodiversity in 1995,
- the establishment of the UN Global IPM Facility in 1995, which provides international guidance and technical assistance for integrated pest management, and
- the signing of the Stockholm Convention on Persistent Organic Pollutants in 2001, so addressing some problematic pesticides.

Policy reform is also underway in many countries, with some new initiatives supporting elements of agricultural sustainability, however progress has been patchy (see Box 4). Most reforms have focused on input reduction strategies, because of concerns over foreign exchange expenditure or environmental damage (Pretty, 1998). But a few countries have given explicit national support to sustainable agriculture, placing it at the centre of agricultural development policy and integrating policies accordingly. For example, Cuba has a national policy for alternative agriculture; and Bhutan has a national environmental policy coordinated across all sectors.

Some countries, such as India, Brazil and Sri Lanka, have seen sub-regional support at the state level for zero-tillage, watershed and soil management, and participatory irrigation management. And a much larger number of countries have reformed elements of their agricultural policies through new regulations, incentives and/or environmental taxes and administrative mechanisms (Pretty, 2003). Specific examples include:

- Indonesia's ban on pesticides and programme for farmer field schools;
- Bolivia's regional integration of agricultural and rural policies;
- Burkina Faso's land policy; and
- Sri Lanka and the Philippines' stipulation that water users' groups be formed for irrigation system management.

And, in an even larger number of countries, some progress has been seen on agricultural sustainability at the project and programme level. However, progress on the ground still remains largely despite of, rather than because of, explicit policy support.

BOX 4: Survey of sustainable agriculture initiatives

The University of Essex recently completed the largest ever survey of sustainable agriculture initiatives in developing countries, covering more than 280 projects in 57 countries. Researchers found improvements in food production occurring through one or more of four mechanisms:

1. Intensification of a single component of a farm system.
2. Addition of a new productive element to a farm system.
3. Better use of water and land, so increasing cropping intensity.
4. Improvements in per hectare yields of staples through introduction of new regenerative elements into farm systems and new locally appropriate crop varieties and animal breeds.

The study found that sustainable agriculture practices had led to an average 93% increase in per hectare food production. The relative yield increases were greater at lower yields, indicating greater benefits for poor farmers, and for those missed by the recent decades of modern agricultural development.

A good example of a carefully designed and well-integrated programme comes from China. In March 1994, the government published a White Paper to set out its plan for implementation of Agenda 21, and put forward ecological farming, known as *Shengtai Nongye* or agroecological engineering, as the approach to achieve sustainability in agriculture. Pilot projects were established in 2000 in townships and villages spread across 150 counties. Policy for these 'eco-counties' is organised through a cross-ministry partnership, which uses a variety of incentives to encourage adoption of diverse production systems to replace monocultures. These include subsidies and loans, technical assistance, tax exemptions and deductions, security of land tenure, marketing services and linkages to research organisations. These eco-counties contain some 12 million hectares of land, about half of which is cropland, and though only covering a relatively small part of China's total agricultural land, illustrate what is possible when policy is appropriately coordinated (Li Wenhua, 2001).

In the last few decades, efforts have been made to put in a place a global agricultural research system, known as the Consultative Group for International Agricultural Research (CGIAR), to enable the farmers of the developing world to meet the challenge of future food demands. The environmental community has called for a stronger ecological approach in the CGIAR research agenda and newer centres within the Group have reflected a shift from an almost exclusive focus on crop and animal productivity to a broader research programme that includes the resource and environmental basis on which agricultural production rests. By the late 1990s, approximately 30% of the research budget of CGIAR

centres was directed to areas of environmental protection and biodiversity preservation (Ruttan, 2000).

As the following section highlights, progress in developing and implementing appropriate policy responses to promote agricultural sustainability has to some extent been hampered by strongly divergent opinion on the best way forward.

3. Areas of debate

3.1 Competing ideas on the way forward

All commentators agree that food production will have to increase substantially over the coming years. But there are very different views about the best way to achieve this (Trewevas, 2002; Smil, 2000; Tilman et al., 2002; McNeely and Scherr, 2003; Pretty, 2002; Nuffield Council on Bioethics, 2004; NRC, 2000; Avery, 1995). Pretty (1998) identifies five competing sets of ideas about the future of world food production:

1. *Environmental pessimists* contend that the ecological limits on further agricultural growth are being approached or have already been reached. They do not believe that new technological breakthroughs are likely and that only population control will prevent a Malthusian crisis.
2. *Business-as-usual optimists* believe that market forces will ensure that supply will always meet increasing demand and that world food production will continue to grow alongside expected reductions in population growth. They argue food prices are falling, and that biotechnology will provide the latest set of technical measures to increase supply.
3. The "*industrialized world to the rescue*" lobby believes that developing countries will never be food self-sufficient, for a wide range of ecological, institutional and infrastructural reasons. They see that the food gaps will have to be filled by modernized agriculture in the industrialized countries. Increasing production in large, mechanized operations will force smaller and more marginal farmers to go out of business, taking the pressure off natural resources.

The two remaining groups believe that significant yield increases are possible, but are divided over the most appropriate way to achieve these.

4. *New modernists* advocate an extension of Green Revolution, high external input farming to areas such as Africa that have so far seen limited use of such techniques. This group argues that farmers use too few fertilizers and pesticides, which are said to be the only way to improve yields from natural habitats. It also argues that high-input agriculture is more environmentally sustainable than low-input agriculture, which makes intensive use of local resources that, may be degraded in the process.

5. *Sustainable intensification* advocates argue that it is possible to raise yields while conserving the environment, using intermediate or low-input techniques.

But solving the persistent hunger problem is not simply a matter of developing new agricultural technologies and practices. Most poor producers cannot afford expensive technologies. They will have to find new types of solutions based on locally-available and/or cheap technologies combined with making the best of natural, social and human resources.

These challenges mean opinion is still strongly divided (Conway, 1997). For example, some say organic agriculture is the only approach that can work to increase agricultural production; others are worried by its lower productivity in industrialized countries. Some say genetic modification offers new opportunities to breed crops and animals with new traits; whilst others say these technologies are unsafe or centralize power in food systems.

3.2 Extensive vs intensive approaches to agricultural sustainability

A common, though erroneous, assumption has been that agricultural sustainability approaches imply a net reduction in input use, and so are essentially extensive (they require more land to produce the same amount of food). All recent empirical evidence shows that successful agricultural sustainability initiatives and projects arise from changes in the factors of agricultural production (e.g. from use of fertilizers to nitrogen-fixing legumes; from pesticides to emphasis on natural enemies). However, these have also required reconfigurations of human capital (knowledge, management skills, labour) and social capital (capacity to work together) (Li Wenhua, 2001; Uphoff, 2002; Pretty and Ward, 2001).

Pretty argues that a better concept than extensive, is to suggest that sustainability implies intensification of resources – making better use of existing resources (e.g. land, water, biodiversity) and technologies. For many, the term intensification has come to imply something bad – referring, for example, in industrialised countries to agricultural systems that impose significant environmental costs. The critical question however centres on the ‘type of intensification’.

Intensification using natural, social and human capital assets, combined with the use of the best available technologies and inputs (best genotypes and best ecological management) that minimise or eliminate harm to the environment, can be termed ‘sustainable intensification’ (Pretty et al., 2003b).

Agricultural sustainability emphasises the potential dividends that can come from making the best use of the genotypes (G) of crops and animals and the ecological (E) conditions under which they are grown or raised. The outcome is a result of this G×E interaction. Agricultural sustainability, therefore, suggests a focus on both genotype improvements

through the full range of modern biological approaches, as well as improved understanding of the benefits of ecological and agronomic management and manipulation (Pretty, 2002).

3.3 The role of biotechnology

Biotechnology is a particular source of contention, as some believe it cannot benefit poorer farmers. However, a recent review by the Nuffield Council on Bioethics gave examples of pro-poor applications that are already working or have shown some promise (Nuffield Council on Bioethics, 2004). Two questions need to be asked when considering the potential benefits of genetically modified (GM) crops in developing countries (Pretty, 2001):

- Does the new GM crop replace an existing technology or practice that is more harmful to the environment or human health? (e.g. *Bt* cotton in China, which is replacing a form of management dependent on very high levels of pesticide use).
- Does the new GM crop address a problem that has not been solved by existing research? (e.g. viral-resistant cassava, potatoes, sweet potatoes, rice and maize; nematode-resistant bananas; thermo-tolerant and drought-tolerant pearl millet; and *Striga*-resistant maize).

Agricultural sustainability is not an ideological or normative condition for describing farming and food systems. The idea of agricultural sustainability does not mean ruling out any technologies or practices on ideological grounds. If a technology works to improve productivity for farmers, and does not harm the environment, then it is likely to be beneficial on sustainability grounds. There are, however, two levels:

- A "light green" approach to sustainability suggests priorities for agricultural systems that cause no harm to the environment or human health.
- A "dark green" approach to sustainability suggests priorities for agricultural systems that help to build important natural and social assets whilst producing more food.

It is clear that any production of public goods (for those who cannot afford their purchase) is unlikely from the private sector, thus emphasising the need for intervention by the public sector or agencies working in the public interest.

4. Closing the gap

Our understanding of poverty–agriculture–environment interactions and their importance to sustainable economic development has advanced considerably in recent years. The challenge of the twenty-first century will be to make the transition to sustainable growth. However, our capacity to respond effectively is still limited, in part by existing institutional weaknesses and remaining knowledge gaps.

4.1 Knowledge gaps

Measuring externalities

Partly as a result of lack of information, there is little agreement on the economic costs of externalities in agriculture. Some authors suggest that the current system of economic calculations grossly underestimates the current and future value of natural capital (Constanza et al., 1997; Daily, 1997). Such valuations of ecosystem services remain controversial because of methodological and measurement problems and because of their role in influencing public opinions and policy decisions (Hanley et al., 1998; Carson, 2000).

Scale and measurement

One challenge is to select appropriate scales of analysis and to measure agricultural sustainability at different levels – plant, farm, farming system, regional or national.

Addressing climate change and water shortages

What we do not know is how best to address the problems likely to come with climate change, and how to increase water use efficiency for all crops. A challenge will be to design effective insurance schemes and offer practical options to ensure poor farmers have access to climate forecasting information and crop advice to help manage risk.

Scaling up approaches to agricultural sustainability

Here the questions are: How to scale up relatively small-scale successes to whole regions and countries? What are the best incentives, policies and institutional configurations?

Agronomic information

In order to introduce efficient measures that favour sustainability in agricultural production – particularly in intensive cereal cultivation systems – there is a need for better global and regional agronomic information.

Setting sustainability targets

Policy-makers are constrained by a lack of information about how to bring about desired outcomes in increased agricultural production and poverty reduction, whilst sustaining the resource base. There is uncertainty about how to set sustainability targets, assess the short- and long-term costs, and how to go about reaching these targets.

4.2 Conclusion

New incentives and policies for ensuring the sustainability of agriculture will be crucial if we are to meet the demands of improving yields without comprising environmental integrity or public health (Tilman et al., 2002). Given emerging pressures and resource constraints, agricultural policies need to simultaneously help meet the triple objectives of poverty reduction, agricultural production and environmental sustainability. A major challenge is to create policies, institutions and technologies that make the three goals more compatible. To maximize agriculture's efficiency and sustainability, public policy should seek to internalize all costs and benefits in the prices of production inputs, such as improving pricing mechanisms for irrigation water, facilitating land market development, and eliminating

distorting taxes and subsidies on agrochemical inputs, including fertilizers (World Bank, 2003). Secure property rights and other policies offering farmers incentives for investing in resource management, as well as access to yield-increasing and resource-conserving technologies are critical.

Recently, many donor assistance agencies have re-engaged in agricultural policy debates following increased recognition that poverty reduction and economic growth cannot be achieved without substantial improvements in agricultural productivity. A key priority for donor agencies will be to engage with developing country governments to place the concept of sustainability at the centre of agricultural policy-making and implementation, and to incorporate emerging ideas about agricultural sustainability into strategies for wider poverty reduction.

BOX 5: Key policy areas for agricultural sustainability (Pretty, 1998, 2002)

Pretty highlights the following key policy areas for agricultural sustainability:

- invest in public research and extension systems for adapting and transferring technologies;
- provide technical assistance and capacity-building for ministries of agriculture and natural resource management;
- invest in both dryland and wetland water management systems to increase water productivity;
- engage in debate with recipient countries over appropriate land reform, as poor people cannot be expected to invest in asset building (especially of natural capital) if they have no guarantee over long-term access to their land;
- promote support for agricultural development programmes that build rural social capital, particularly for women, to access credit and microfinance;
- develop new approaches for supporting small-scale agribusinesses in rural areas (so that food commodities can be value-added before leaving the local economy), such as loan guarantees, underwriting debt, providing equity funds, and providing grants for social infrastructure and community projects;
- ensure support for urban agriculture;
- work with farmers' and rural people's organisations to develop better methods for accessing market information.
- take a regional approach – emphasise structural reforms and support within specified regions to maximise synergies between different sectors, actors and resources;
- develop partnerships and use participatory approaches – with implementing and policy non-government organisations (NGOs), CGIAR institutes and national research and extension systems, the private sector, and policy-making departments;
- ensure that policy-making is evidence-based by developing good monitoring and lesson-learning systems;
- integrate the concept of agricultural sustainability into poverty reduction

strategies and policies, in particular measure all agricultural and rural development strategies against the primary target of mass, pro-poor farm-based progress;

- provide long-term support – there is no simple ‘magic bullet’ for agricultural development, and agencies involved for the long-term see the greatest impacts;
- increase support for research, which in some disciplines is increasingly being privatised and driven to specialise in the farming systems of the rich, rather than addressing the need for sustainable intensification of farming for the employment-intensive poor.

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