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Reducing food poverty by increasing agricultural sustainability in developing countries

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Abstract

We examined the extent to which farmers have improved food production in recent years with low cost, locally available and environmentally sensitive practices and technologies. We analysed by survey during 1999–2000 208 projects in 52 developing countries, in which 8.98 million farmers have adopted these practices and technologies on 28.92 million hectares, representing 3.0% of the 960 million hectares of arable and permanent crops in Africa, Asia and Latin America. We found improvements in food production occurring through one or more of four mechanisms: (i) intensification of a single component of farm system; (ii) addition of a new productive element to a farm system; (iii) better use of water and land, so increasing cropping intensity; (iv) 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 89 projects with reliable yield data show an average per project increase in per hectare food production of 93%. The weighted average increases across these projects were 37% per farm and 48% per hectare. In the 80 projects with small (<5 ha) farms where cereals were the main staples, the 4.42 million farms on 3.58 million hectares increased household food production by 1.71 t per year. We report on the practices and technologies that have led to these increases: increased water use efficiency, improvements to soil health and fertility, and pest control with minimal or zero-pesticide use. This research reveals promising advances in the adoption of practices and technologies that are likely to be more sustainable, with substantial benefits for the rural poor. With further explicit support, particularly through national policy reforms and better markets, these improvements in food security could spread to much larger numbers of farmers and rural people in the coming decades.

Keywords: Agricultural sustainability; Food security; Rural livelihoods; Policies

1. Introduction

Over the past 40 years, per capita world food production has grown by 25%, with average cereal yields rising from 1.2 to 2.52 t ha^{-1} in developing countries (to 1.71 t ha^{-1} on rainfed lands and to 3.82 t ha^{-1} on irrigated lands), and annual cereal production up from 420 to 1176 million tonnes (FAO, 2000). These global increases have helped to raise average per capita consumption of food by 17% over 30 years to 2760 kcal per day, a period during which world population grew from 3.69 to 6.0 billion. Despite such advances in productivity, the world still faces a persistent food security challenge. There are an estimated 790 million people lacking adequate access to food, of whom 31% are in east and south-east Asia,

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31% in South Asia, 25% in Sub-Saharan Africa, 8% in Latin America and the Caribbean, and 5% in North Africa and near east (Pinstrup-Anderson et al., 1999; Uphoff, 2002). A total of 33 countries still have an average per capita food consumption of less than 2200 kcal per day (FAO, 2000).

An adequate and appropriate food supply is a necessary condition for eliminating hunger. But increased food supply does not automatically mean increased food security for all. A growing world population for at least another half century, combined with changing diets arising from increasing urbanisation and consumption of meat products, will bring greater pressures on the existing food system (Popkin, 1998; Delgado et al., 1999; Pinstrup-Anderson et al., 1999; UN, 1999; ACC/SCN, 2000; Smil, 2000). If food poverty is to be reduced, then it is important to ask who produces the food, who has access to the technology and knowledge to produce it, and who has the purchasing power to acquire it? Modern agricultural methods have been shown to be able to increase food production, yet food poverty persists. Poor and hungry people need low cost and readily available technologies and practices to increase food production. A further challenge is that this needs to happen without further damage to an environment increasingly harmed by existing agricultural practices (Pretty et al., 2000; Wood et al., 2000; McNeely and Scherr, 2001).

2. Key questions for research on agricultural sustainability

There are three strategic options for agricultural development if food supply is to be increased:

i. Expand the area of agriculture, by converting new lands to agriculture, but resulting in losses of ecosystem services from forests, grasslands and other areas of important biodiversity.
ii. Increase per hectare production in agricultural exporting countries (mostly industrialised), but meaning that food still has to be transferred or sold to those who need it, whose very poverty excludes these possibilities.
iii. Increase total farm productivity in developing countries which most need the food, but which have not seen substantial increases in agricultural productivity in the past.

In this research, we explore the capacity to which more sustainable technologies and practices can address the third option. We draw tentative conclusions about the value of such approaches to agricultural development. This is not to say that industrialised agriculture cannot successfully increase food production. Manifestly, any farmer or agricultural system with unlimited access to sufficient inputs, knowledge and skills can produce large amounts of food. But most farmers in developing countries are not in such a position, and the poorest generally lack the financial assets to purchase costly inputs and technologies. The central questions, therefore, focus on:

(i) To what extent can farmers increase food production by using low cost and locally available technologies and inputs?
(ii) What impacts do such methods have on environmental goods and services and the livelihoods of people who rely on them?

The success of industrialised agriculture in recent decades has often masked significant environmental and health externalities (actions that affect the welfare of or opportunities available to an individual or group without direct payment or compensation). Environmental and health problems associated with industrialised agriculture have been well documented (cf. Balfour, 1943; Carson, 1963; Conway and Pretty, 1991; EEA, 1998; Wood et al., 2000), but it is only recently that the scale of the costs has come to be appreciated through studies in China, Germany, UK, the Philippines and the USA (Steiner et al., 1995; Pimentel et al., 1995; Pingali and Roger, 1995; Waibel and Fleischer, 1998; Norse et al., 2000; Pretty et al., 2000, 2001).

What do we understand by agricultural sustainability? Systems high in sustainability are making the best use of nature's goods and services whilst not damaging these assets (Altieri, 1995; Pretty, 1995, 1998; Thrupp, 1996; Conway, 1997; Hinchcliffe et al., 1999; NRC, 2000; Li Wenhua, 2001; McNeely and Scherr, 2001; Uphoff, 2002). The aims are to: (i) integrate natural processes such as nutrient cycling, nitrogen fixation, soil regeneration and natural enemies of pests into food production processes; (ii) minimise the use of non-renewable inputs that damage the environment or harm the health of farmers and consumers; (iii) make productive use of the knowledge and skills of farmers, so improving their self-reliance and substituting human capital for costly inputs; (iv) make productive use of people's capacities to work together to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest and credit management.

Agricultural systems emphasising these principles are also multi-functional within landscapes and economies. They jointly produce food and other goods for farm families and markets, but also contribute to a range of valued public goods, such as clean water, wildlife, carbon sequestration in soils, flood protection, groundwater recharge, and landscape amenity value. As a more sustainable agriculture seeks to make the best use of nature's goods and services, so technologies and practices must be locally adapted. They are most likely to emerge from new configurations of social capital, comprising relations of trust embodied in new social organisations, and new horizontal and vertical partnerships between institutions, and human capital comprising leadership, ingenuity, management skills, and capacity to innovate. Agricultural systems with high levels of social and human assets are more able to innovate in the face of uncertainty (Uphoff, 1999; Pretty and Ward, 2001).

3. Research methods

The aim of the research was to audit recent progress in agricultural sustainability in developing countries. We accessed an international network of key professionals in the field of agricultural sustainability and food security, and asked them both to suggest projects and initiatives, and to pass on details of this research project to other relevant people or institutions. We also accessed other datasets (e.g. Hinchcliffe et al., 1996; FAO, 1999). We asked for nominations for three types of initiatives: (i) research projects with active farmer involvement, but which may not yet have spread; (ii) community-based projects with proven impacts; (iii) regional projects/initiatives that have spread to many communities. We use the term 'project/initiative' here, as these have emerged from many types of institutional context—some are international development projects, some are activities within government programmes, some are non-government organisation or private company led, and some are promoted entirely by farmers' organisations themselves.

We developed a four-page questionnaire as the survey instrument, with a short descriptive rationale on agricultural sustainability and the aims of this research project. The questionnaire survey instrument was based on an assets-based model of agricultural systems, and was developed to understand both the role of these assets as inputs to agriculture and the consequences of agriculture upon them (Conway, 1997; Pretty, 2000; Pretty and Hine, 2000). The questionnaire addressed key impacts on total food production, and on natural, social and human capital, the project/initiative structure and institutions, details of the context and reasons for success, and spread and scaling-up (institutional, technical and policy constraints). The questionnaire was sent out in English, French and Spanish to all potential projects by email and conventional post in early 1999. Field operatives from nodal organisations were contacted with specific requests and questionnaires. Each project was contacted with a personalised covering letter and questionnaire, and the resultant high response rate (some 60% of those contacted replied with some information) appears to be a consequence of this personal contact. Some 200 reminders and questionnaires were sent out by email in autumn 1999 to attempt to access those who had not yet answered. Follow-up contacts were made to many of these during the course of the year 2000. In a number of instances, we received secondary data on the project rather than a completed questionnaire. We collated returned questionnaires and secondary material, and added these to country files. All datasets were re-examined to identify gaps, and correspondents contacted again.

Not all proposed cases were accepted for the dataset, and rejections were made: (i) where there was no obvious link to agricultural sustainability; (ii) where payments were used to encourage farmer participation, as there have long been doubts that ensuing improvements persist after such incentives end; (iii) where there was heavy reliance on fossil-fuel derived inputs, or only on their targeted use (this is not to negate these technologies, but to simply indicate that they were not the focus of this research); (iv) where the data provided was too weak or the findings unsubstantiated. We also acknowledge that just because projects/initiatives have been accepted for this dataset, this does not necessarily mean they will be sustained indefinitely. The problem of agricultural development activities not persisting beyond the end of projects has been widely analysed through post-project reviews (Bunch, 1983; Chambers, 1983; Cernea, 1991; Carter, 1995). However, we do have confidence about these projects/initiatives, as farmers are adopting novel technologies and practices on their own terms and because they pay—not because they are being offered distorting incentives to do what an external agency wishes.

The questionnaires were self-completed, so were subject to potential bias. We therefore established trustworthiness checks through checks with secondary data, by critical review by external reviewers and experts, and by engaging in regular personal dialogue with respondents. We verified projects by sending full details entered on the database to the named verifier on the questionnaire. We also sent batches of projects to key authorities to obtain a second or third view on the project. This research, therefore, comprises a purposive sample of existing 'best practice' projects/initiatives explicitly addressing agricultural sustainability. It was not a random sample of all agricultural projects, and thus the findings are not representative of all developing country farms. Our aim was to discover the impacts of existing initiatives, to understand the processes and policies that encouraged or restricted them, and to indicate the potential for addressing food poverty through a focus on agricultural sustainability.

4. Survey results

This was the largest known survey of sustainable agricultural practices and technologies in developing countries, with 45 projects in Latin America, 63 in Asia and 100 in Africa, in which 8.98 million farmers have adopted more sustainable practices and technologies on 28.92 million hectares. As there are 960 million hectares of land under cultivation (arable and permanent crops) in Africa, Asia and Latin America, more sustainable practices are now present on at least 3.0% of this land (total arable land comprises some 1600 million hectares in 1995/1997, of which 388 million hectares are in industrialised countries, 267 million hectares in transition countries, and 960 million hectares in developing countries; FAO, 2000).

The most common country representations in the dataset are India (23 projects/initiatives); Uganda (20); Kenya (17); Tanzania (10); China (8); Philippines (7); Malawi (6); Honduras, Peru, Brazil, Mexico, Burkina Faso and Ethiopia (5) and Bangladesh (4). The projects range very widely in scale—from 10 households on 5 ha in one project in Chile to 200,000 farmers on more than 10 million hectares in southern Brazil. Most of the farmers in the projects surveyed are small farmers. Of farms in the total dataset, 50% are in projects with a mean area per farmer of less than 1 ha, and 90% with less than or equal to 2 ha (Fig. 1a and b). Thus of the total, there are some 8.64 million small farmers practising forms of more sustainable farming on 8.33 million hectares. Most of these initiatives increasing agricultural sustainability have emerged in the past decade. Using project records, we estimate that the area a decade ago in these 208 initiatives was no more than 500,000 ha.

5. Changes in farm and household food productivity

We found improvements in food production were occurring through one or more of four different mechanisms:

i. The intensification of a single component of a farm system, with little change to the rest of the farm, such as home garden intensification with vegetables or tree crops, vegetables on rice bunds, and introduction of fish-ponds or a dairy cow.
ii. The addition of a new productive element to a farm system, such as fish or shrimps in paddy rice fields, or trees, which provide a boost to total farm food production and/or income, but which do not necessarily affect cereal productivity.
iii. The better use of natural resources to increase total farm production, especially water (by water harvesting and irrigation scheduling), and land (by reclamation of degraded land), so leading to additional new dryland crops and/or increased supply of additional water for irrigated crops (both increasing cropping intensity).
iv. Improvements in per hectare yields of staple cereals through introduction of new regenerative

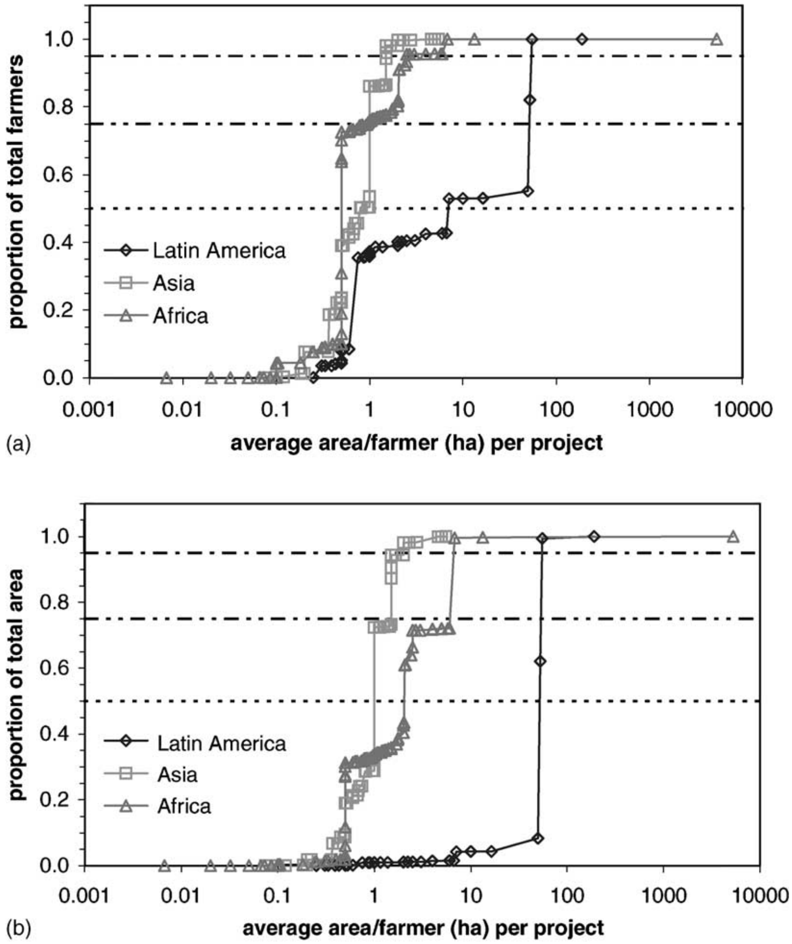

Fig. 1. (a) Cumulative proportion of farmers by project size according to region (dotted horizontal lines represent 50, 75 and 95% of total farmers). (b) Cumulative proportion of total area by project size according to region (dotted horizontal lines represent 50, 75 and 95% of total area).

elements into farm systems, such as legumes and integrated pest management, and new and locally appropriate crop varieties and animal breeds.

Thus a successful project increasing agricultural sustainability may be substantially improving domestic food consumption or increasing local food barters or sales through home gardens or fish in rice fields, or better water management, without necessarily affecting the per hectare yields of cereals. Fig. 2 illustrates the frequency of occurrence of each of these mechanisms in the dataset. The most common mechanisms were yield improvements with regenerative technologies and new seeds/breeds, occurring in 60% of the projects, by 56% of the farmers and over 89% of the area. Home garden intensification occurred in 20% of projects, but given its small-scale only accounted for 0.7% of area. Better use of land and water, giving rise to increased cropping intensity, occurred in 14% of projects, with 31% of farmers and 8% of the area. The incorporation of new productive elements into farm systems, mainly fish/shrimps in paddy rice, occurred in 4% of projects, and accounted for the smallest proportion of farmers and area.

As mechanism 4 was the most common, we analysed these projects in greater detail. The dataset

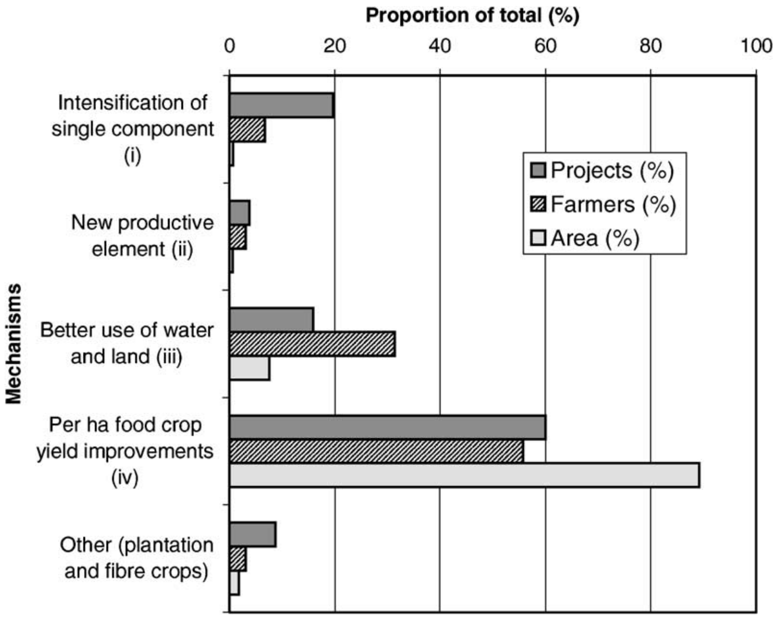

Fig. 2. Frequency of occurrence of each type of improvement mechanism by projects, farmers and area (data from SAFE-World research project).

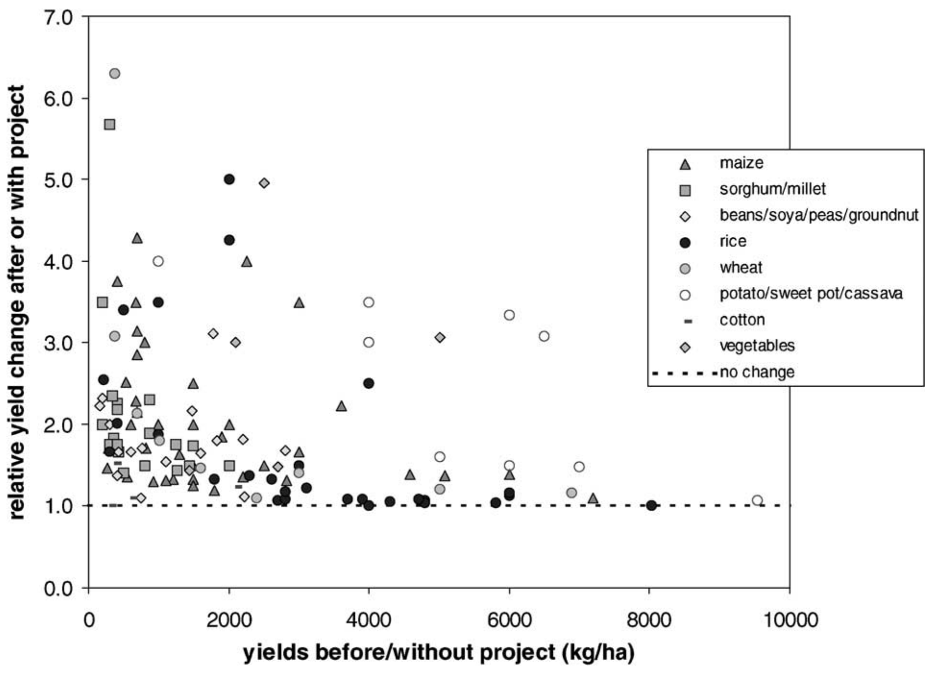

Fig. 3. Relative crop yield changes in agricultural sustainability projects/initiatives (89 projects) (data from SAFE-World research project).

contains 89 projects (139 entries of crop × projects combinations) with reliable data on per hectare yield changes with mechanism 4, and these are shown as relative yield changes over a baseline of 1.0 according to yields before or without the interventions (Fig. 3). Agricultural sustainability has led to a 93% increase in per hectare food production through mechanism 4 averaged across all projects. The weighted averages are a 37% increase per farm household, and a 48% increase per hectare in these projects. The relative yield increases are higher at lower yields, indicating greater benefits for poor farmers, most of whom have been missed by recent decades of agricultural development. We also analysed the yield data according to crop types (Fig. 4). The largest relative increases in yield occur for vegetables and roots, and the smallest for rice and beans/soya/peas.

We also calculated the marginal increase in food production per household for these 89 projects with reliable data on yields, area and numbers of farmers. Using the data for average farm size in each project, we calculated the average increase in annual food production per household after adoption of more sustainable practices and technologies (Fig. 5). In the 80 projects with small (<5 ha) farms where cereals were the main staples, the 4.42 million farms on 3.58 million hectares increased household food production by 1.71 t per year (an increase of 73%). In the 14 projects with roots as main staples (potato, sweet potato and cassava), the 146,000 farms on 542,000 ha increased household food production by 17 t per year (increase of 150%). In the four projects in southern Latin America with larger farm size (average size of 90 ha per farm), household production increased by 150 t per year (increase of 46%).

These aggregate figures understate the benefits of increased diversity in the diet as well as increased quantity. Most of these agricultural sustainability initiatives have seen increases in farm diversity. In many cases, this translates into increased diversity of food consumed by the household, such as availability of fish protein from rice fields or fish-ponds, milk and animal products from dairy cows, poultry and pigs kept in the home garden, and vegetables and fruit from home gardens and other farm micro-environments. Although these initiatives are reporting significant increases in food production, some as yield improvements, and some as increases in cropping intensity or diversity of produce, few are reporting surpluses of food being sold to local markets. We suggest this is because of a significant elasticity of consumption amongst rural households in this dataset experiencing any degree of

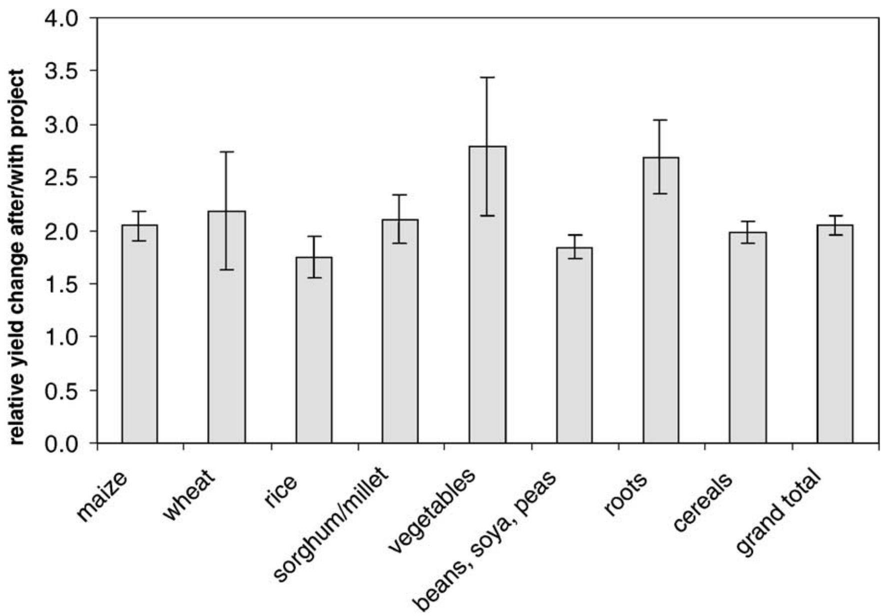

Fig. 4. Relative change in yield grouped by crop type (mean and ±S.E.M.) (data from SAFE-World research project).

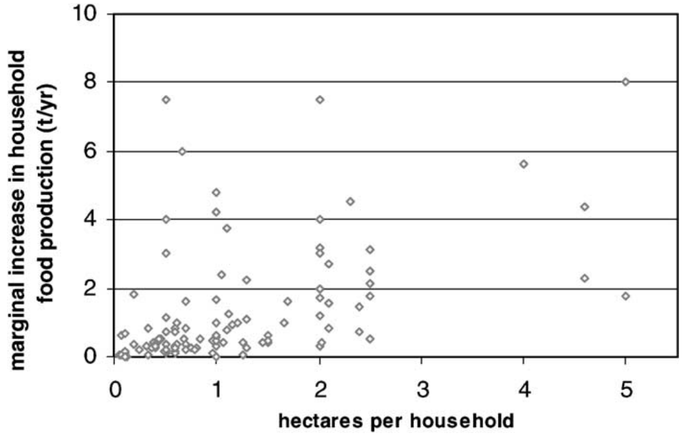

Fig. 5. Change in annual household food production with sustainable agricultural practices and technologies (data from SAFE-World research project).

food insecurity. As production increases, so also does domestic consumption, with direct benefit particularly for the health of women and children.

As indicated earlier, for an average farm size of 1.4 ha (for the 4.4 million households for which good data exists), the annual increase in gross food production (not including root crops) was 1.71 t. The net amount of food available to each household will, of course, be lower than this—owing to post-harvest losses to pests, conversion of harvested crops to consumable food, and feeding of some as feed to animals. Assuming a worst case of 30% loss to pests, and a further 30% reduction in available food, this still leaves 800 kg of available food per household. This is sufficient to feed two adults or one adult with two children for a whole year.

We acknowledge that these findings on agricultural sustainability may sound too good to be true for those who would disbelieve these advances. Many still believe that food production and nature must be separated, that practices increasing agricultural sustainability offer only marginal opportunities to increase food production, and that industrialised approaches represent the best, and perhaps only, way forward (cf. Avery, 1995). However, prevailing views have gradually changed in the last decade, and some sceptics are beginning to recognise the value of innovative capacity emerging from poorer communities in developing countries.

6. Technical options for improving food production and agricultural sustainability

We discern in the dataset three types of technical improvement that have played substantial roles in these food production increases:

(i) more efficient water use in both dryland and irrigated farming;
(ii) improvements to soil health and fertility;
(iii) pest and weed control with minimum or zero-pesticide use.

6.1. More efficient use of water

Improvements in the efficiency of water use can benefit both irrigated and rainfed farmers by allowing new or formerly degraded lands to be brought under farming, and to increased cropping intensity on existing lands. In the projects analysed, water harvesting has been widely applied in dryland areas. The Indo-British Rainfed Farming project, for example, works with 230 local groups in 70 villages on water-harvesting, tree planting, and grazing land improvements (Sodhi, 2001). Basic grain yields of rice, wheat, pigeonpeas and sorghum have increased from 400 to 800–1000 kg ha^{-1}, and the increased fodder grass production from the terrace bunds is valued highly for the livestock. Improved water retention has resulted in water tables rising by 1 m over 3–4 years, meaning that an extra crop is now possible for many farmers, thus turning an unproductive season into a productive one.

Women are major beneficiaries. Sodhi (2001) puts it this way: "In these regions, women never had seen themselves at the front edge of doing things, taking decisions, and dealing with financial transactions. The learning by doing approach of the project has given them much needed confidence, skills, importance and awareness". The wider benefits of a transformed agriculture are also evident, as "The project has indirectly affected migration as people are gaining more income locally through the various enterprises carried out in the project. People are now thinking that they must diversify more into new strategies. There has also been a decline in drawing on resources from the forests". Other projects in India have seen similar environmental and social changes (Devavaram et al., 1999; Lobo and Palghadmal, 1999).

In Sub-Saharan Africa, water harvesting is also transforming barren lands. Again, the technologies are not complex and costly. In central Burkina Faso, 130,000 ha of abandoned and degraded lands have been restored with the adoption of *tassas* and *zaï*. These are 20–30 cm holes dug in soils that have been sealed by a surface layer hardened by wind and water erosion. The holes are filled with manure to promote termite activity and enhance infiltration. When it rains, water is channelled by simple stone bunds to the holes, which fill with water, and into which are planted seeds of millet or sorghum. Cereal yields in these regions rarely exceed 300 kg ha^{-1}, yet these improved lands now produce 700–1000 kg ha^{-1}. Reij (1996) calculated that the average family in Burkina Faso using these technologies had shifted from being in annual cereal deficit amounting to 650 kg, equivalent to six-and-a-half months of food shortage, to producing a surplus of 150 kg per year. Furthermore, *tassas* are best suited to landholdings where family labour is available, or where farm labour can be hired, so that this soil and water conservation method has led to a market for young day labourers who, rather than migrating, now earn money by building these structures.

Good organisation also helps to improve irrigated agriculture. Despite great investment, many irrigation systems have become inefficient and subject to persistent conflict. Irrigation engineers assume that they know best how to distribute water, yet can never know enough about the specific conditions and needs of large numbers of farmers. Recent years, though, have seen the spread of programmes to organise farmers into water users' groups, and let them manage water distribution for themselves (Cernea, 1991; Uphoff, 2002). One of the best examples comes from the Gal Oya region in Sri Lanka. Before this approach, Gal Oya was the largest and most run-down scheme in the country. Now, farmers' groups manage water for 26,000 ha of rice fields, and produce more rice crops per year and per unit of water. Moreover, when farmers took control, the number of complaints received by the Irrigation Department about water distribution fell to nearly 0 (Uphoff, 1999). The benefits were dramatically shown during the 1998 drought. According to government, there was only enough water for irrigation of 18% of the rice area. But farmers persuaded the Irrigation Department to let this water through on the grounds that they would carefully irrigate the whole area. Through cooperation and careful management, they achieved a better than average harvest, earning the country $20 million in foreign exchange. Throughout Sri Lanka, 33,000 water users' associations have now been formed—a dramatic increase in local social organisation that has increased farmers' own capacities for problem solving and cooperation, and for using nature more efficiently and effectively to produce more food.

6.2. Improvements in soil health and fertility

Soil health is fundamental for agricultural sustainability, yet is under widespread threat from degradation processes (Cleaver and Schreiber, 1995; World Bank/FAO, 1996; Smaling et al., 1997; Hinchcliffe et al., 1999; Petersen et al., 2000; Koohafkan and Stewart, 2001). Agricultural sustainability starts with the soil by seeking both to reduce soil erosion and to make improvements to soil physical structure, organic matter content, water-holding capacity and nutrient balances. Soil health is improved through the use of legumes, green manures and cover crops, incorporation of plants with the capacity to release phosphate from the soil into rotations, use of composts and animal manures, adoption of zero-tillage, and use of inorganic fertilisers where needed (Reicosky et al., 1997; Sanchez and Jama, 2000). In projects in Central America, the incorporation of nitrogen-fixing legumes into agroecosystems has substantially affected productivity, particularly the velvetbean (*Mucuna pruriens*) (Anderson et al., 2001; Bunch, 2002). This grows rapidly, fixes 150–200 kg N ha^{-1} per year, suppresses weeds, and can produce 35–50 t of biomass ha^{-1} per year (Bunch, 2000; Anderson et al., 2001). Addition of this biomass to soils substantially improves soil organic matter content, and has helped to increase cereal productivity for some 45,000 families in Guatemala, Honduras and Nicaragua.

In the past decade, Latin American farmers have found that eliminating tillage can be highly beneficial for soils. After harvest, crop residues are left on the surface to protect against erosion, and seed is directly planted into a groove cut into the soil. Weeds are controlled with herbicides or cover crops. The fastest uptake of minimum till systems has been in Brazil, where there are now 15 million hectares under *plantio direto* (also called zero-tillage even though there is some disturbance of the soil) mostly in three southern states of Santa Caterina, Rio Grande do Sul and Paraná, and in the central Cerrado. In neighbouring Argentina, there are more than 11 million hectares under zero-tillage, up from less than 100,000 ha in 1990, and in Paraguay, another 1 million hectares of zero-tillage (Sorrenson et al., 1998; Petersen et al., 1999; de Freitas, 1999; Peiretti, 2000; Landers et al., 2001).

Elsewhere in Brazil, the transformations in the landscape and in farmers' attitudes are equally impressive. The Cerrado is a vast area of formerly unproductive lands colonised for farming in the past two decades. These lands needed lime and phosphorus before they could become productive, and now zero-tillage is being widely adopted (Landers et al., 2001). In the early days, there was a widespread belief that zero-tillage was only for large farmers. That has now changed, and small farmers are benefiting from technology breakthroughs developed for mechanical farming. A core element of zero-tillage adoption in South America has been adaptive research—working with farmers at microcatchment level to ensure technologies are fitted well to local circumstances. There are many types of farmers groups: from local (farmer microcatchment and credit groups), to municipal (soil commissions, Friends of Land clubs, commercial farmers and farm workers' unions), to multi-municipal (farmer foundations and cooperatives), to river basin (basin committees for all water users), and to state and national level (state zero-tillage associations and the national zero-tillage federation).

Farmers are now adapting technologies—organic matter levels have sufficiently improved that fertiliser use has been reduced and rainfall infiltration improved, such that some farmers are removing contour terraces. Other side effects zero-tillage include reduced siltation of reservoirs, less flooding, higher aquifer recharge, lowered costs of water treatment, cleaner rivers, and more winter feed for wild biodiversity (Landers et al., 2001). However, there is still controversy over zero-tillage, as some feel the use of herbicides to control weeds, or of genetically modified crops, means we cannot call these systems sustainable. However, the environmental benefits are substantial, and new research is showing that farmers have some effective alternatives, particularly if they use cover crops for green manures to raise organic matter levels. Using 20 species of cover crops and green manures, Petersen and colleagues have shown how small farmers can adopt zero-tillage systems without herbicides (Petersen et al., 2000; von der Weid, 2000).

A public good is also being created when soil health is improved with increased organic matter. Soil organic matter contains carbon, and soils with above-ground biomass can act as 'carbon sinks' or sites for carbon sequestration (Reicosky et al., 1995; Smith et al., 1998; Sanchez et al., 1999; Watson et al., 2000; Pretty and Ball, 2001; Pretty et al., 2002). Conservation tillage systems and those using legumes and/or cover crops contribute to organic matter and carbon accumulation in the soil.

In the Sahelian countries of Africa, the major constraints to food production are also related to soils, most of which are sandy and low in organic matter. In Senegal, where soil erosion and degradation threaten large areas of agricultural land, the Rodale Institute Regenerative Agriculture Resource Center works closely with farmers' associations and government researchers to improve the quality of soils. The primary cropping system of the region is a millet–groundnut rotation. Fields are cleared by burning, and then cultivated with shallow tillage using animals. But fallow periods have decreased dramatically, and inorganic fertilisers do not return high yields unless there are concurrent improvements in organic matter, which helps to retain moisture. The Center collaborates with 2000 farmers organised into 59 groups on improving soil quality by integrating stall-fed livestock into crop systems, adding legumes and green manures, increasing the use of manures, composts and rock phosphate, and developing water-harvesting systems. The result has been a 75–190% improvement in millet and groundnut yields—from about 300 to 600–900 kg ha^{-1}. Yields are also less variable year on year, with consequent improvements in household food security (Diop, 1999).

Thus if the soil is improved, the whole agricultural system's health improves. Even if this is done on a very small-scale, people can benefit substantially. In Kenya, the Association for Better Land Husbandry found that farmers who constructed double-dug beds in their gardens could produce enough vegetables to see them through the hungry dry season. These raised beds are improved with composts, and green and animal manures. A considerable investment in labour is required, but the better water-holding capacity and higher organic matter means that these beds are both more productive and better able to sustain vegetable growth through the dry season. Once this investment is made, little more has to be done for the next 2–3 years. Women in particular are cultivating many vegetable and fruit crops, including kale, onion, tomato, cabbage, passion fruit, pigeon pea, spinach, pepper, green bean and soya. According to one review of 26 communities, 75% of participating households are now free from hunger during the year, and the proportion having to buy vegetables had fallen from 85 to 11%. For too long, agriculturalists have been sceptical about these organic and conservation methods. They say they need too much labour, are too traditional, and have no impact on the rest of the farm. Yet the spin-off benefits are substantial, as giving women the means to improve their food production means that food gets into the mouths of children. They suffer fewer months of hunger, and so are less likely to miss school (Hamilton, 1998).

6.3. Pest control with minimal or zero-pesticide use

Modern farmers have come to depend on a great variety of insecticides, herbicides and fungicides to control pests, weeds and diseases, and each year, some 5 billion kilogram of pesticide active ingredients are applied to farms (BAA, 2000). But farmers in these projects have found many effective and more sustainable alternatives. In some crops, it may mean the end of pesticides altogether, as cheaper and more environmentally benign practices are found to be effective (Power and Kenmore, 2002).

Many projects in our survey reported large reductions in pesticide use in irrigated rice systems. Following the discovery that pest attack on rice was proportional to pesticide use (Kenmore et al., 1984), farmer field schools were later developed to teach farmers the benefits of agro-biodiversity. In Indonesia, 1 million farmers have now attended 50,000 field schools, the largest number in any Asian country. In Vietnam, 2 million farmers have cut pesticide use from more than 3 sprays to 1 per season; in Sri Lanka, 55,000 farmers have reduced use from 3 to 0.5 per season; and in Indonesia, 1 million farmers have cut use from 3 sprays to 1 per season. In no case has reduced pesticide use led to lower rice yields (Eveleens et al., 1996; Heong et al., 1998; Mangan and Mangan, 1998; Barzman and Desilles, 2002; Jones, 2002). Amongst these are reports that many farmers are now able to grow rice entirely without pesticides: 25% of field school trained farmers in Indonesia, 20–33% in the Mekong Delta of Vietnam and 75% in parts of the Philippines.

If pesticides are removed, then fish can be reintroduced. In Bangladesh, an aquaculture and integrated pest management programme implemented by CARE has completed 6000 farmer field schools, resulting in 150,000 farmers adopting more sustainable methods of rice production on about 50,000 ha. The programme emphasises fish cultivation in paddy fields, and vegetable cultivation on rice field dykes. Rice yields have improved by 5–7%, and costs of production have fallen owing to reduced pesticide use. In addition, each hectare of paddy yields up to 750 kg of fish, a significant increase in system productivity for poor farmers with few resources (Rashid, 2001).

In Kenya, intercropping of local legumes and grasses with maize has been found to reduce stem borer (*Chilo* spp.) attack through interactions with parasitic wasps. Researchers call their redesigned and diverse maize fields *vutu sukuma* (push–pull systems, as they manipulate predators, parasites and prey). More than 2000 farmers in western Kenya have adopted maize, grass-strip and legume-intercropping systems, and have increased maize yields by 60–70%. The official advice to maize growers in the tropics has been to create monocultures for modern varieties of maize, and then apply pesticide and fertilisers to make them productive. Yet this very simplification eliminated vital and free pest management services produced by the grasses and legumes. *Vutu sukumu* systems are complex and diverse, and are cheap as they do not rely on costly purchased inputs (Khan et al., 2000).

Another project in Yunnan, China has shown the value of mixtures of rice, both in reducing disease incidence and increasing yields (Zhu et al., 2000; Wolfe, 2000). Researchers working in 10 townships on 5350 ha encouraged farmers to switch from growing monocultures of sticky rice to alternating rows of sticky rice with hybrids. The sticky rice brings a higher price, but is susceptible to rice blast, which is generally controlled through application of fungicides. But planting mixtures in the same field reduced blast incidence by 94% and increased total yields by 89%. By the end of 2 years, it was concluded that fungicides were no longer required.

7. Impacts on rural livelihoods and economies

Rural people's livelihoods rely for their success on the value of services flowing from the total stock of natural, social, human, physical and financial capital (Coleman, 1990; Putnam et al., 1993; Costanza et al., 1997; Carney, 1998; Scoones, 1998; Pretty and Ward, 2001). A number of examples can be extracted from the dataset to show that agricultural sustainability projects and initiatives have been able to contribute to the accumulation of locally valuable assets. A selection of the impacts reported in these sustainable agriculture projects and initiatives include:

(i) Improvements to natural capital, including increased water retention in soils, improvements in water table (with more drinking water in the dry season), reduced soil erosion combined with improved organic matter in soils, leading to better carbon sequestration, and increased agro-biodiversity (cf. Hinchcliffe et al., 1999; Watson et al., 2000; McNeely and Scherr, 2001; Pretty and Ball, 2001).

(ii) Improvements to social capital, including more and stronger social organisations at local level, new rules and norms for managing collective natural resources, and better connected to external policy institutions (cf. Uphoff, 1999; Pretty and Ward, 2001).

(iii) Improvements to human capital, including more local capacity to experiment and solve own problems; reduced incidence of malaria in rice–fish zones, increased self-esteem in formerly marginalised groups, increased status of women, better child health and nutrition, especially in dry seasons, and reversed migration and more local employment (cf. Li Kangmin, 1998; Shah and Shah, 1999; Bunch, 2000; Rengasamy et al., 2000; Pretty and Uphoff, 2002).

The empirical evidence indicates that some improvements in agricultural sustainability have had positive effects on regional economies. In the Ansokia valley, Ethiopia, one project increased annual food production from 5600 to 8370 t in 6 years, at the same time as the population increased from 36,000 to 45,000. The project turned around an annual food regional deficit of −2106 t to a surplus of 372 t per year. In Bushenyi, Uganda, formerly experiencing substantial food shortages during the months of October–December, one project so increased banana and cattle production that the region could sells 330 t bananas and 2.7 t of meat each week. In En Nahud, Sudan, the 10,000 t of additional food produced by 15,000 households were consumed by local people. None found its way into national statistics.

There is also evidence that productivity can increase over time as natural and human capital assets increase. If agricultural systems are low in capital assets (either intrinsically low, or have become low because of degradation), then a sudden switch to 'more sustainable' practices that have to rely on these assets will not be immediately successful. In Cuba, for example, urban organic gardens produced 4200 t of food in 1994. By 1999, they had greatly increased in per area productivity—rising from 1.6 to 19.6 kg m^{-2} (Murphy, 1999; Funes, 2001). Increasing productivity over time has also been noted in fish-ponds in Malawi. These are typically some 200–500 m^2 in size. Researchers compared the performance of 35 fish-ponds over 6 years; in 1990 yields were 800 kg ha^{-1}, but rose steadily to 1450 kg ha^{-1} by 1996. This is because fish-ponds are integrated into a farm so that they recycle wastes from other agricultural and household enterprises, leading to steadily increasing productivity over time as farmers themselves gain understanding (Brummet, 2000).

8. Confounding factors and trade-offs

What we do not yet know is whether moving to more sustainable systems, delivering greater benefits at the scale occurring in these projects, will result in enough food to meet the current food needs in developing countries, let alone the future needs after continued population growth and adoption of more urban and meat-rich diets (Delgado et al., 1999). But what we are seeing should be cause for cautious optimism, particularly as evidence indicates that productivity can grow over time if natural, social and human assets are accumulated (see also McNeely and Scherr, 2001; Uphoff, 2002).

A more sustainable agriculture which improves the asset base can lead to rural livelihood improvements. People can be better off, have more food, be better organised, have access to external services and power structures, and have more choices in their lives. But like all major changes, such transitions can also provoke secondary problems. For example, building a road near a forest can help farmers reach food markets, but also aid illegal timber extraction. Projects may be making considerable progress on reducing soil erosion and increasing water conservation through adoption of zero-tillage, but still continue to rely on applications of herbicides. If land has to be closed off to grazing for rehabilitation, then people with no other source of feed may have to sell their livestock; and if cropping intensity increases or new lands are taken into cultivation, then the burden of increased workloads may fall particularly on women. Also additional incomes arising from sales of produce may go directly to men in households, who are less likely than women to invest in children and the household as a whole.

There are also a variety of emergent factors that could slow down the spread of agricultural sustainability. First, practices that increase the asset base may simply increase the incentives for more powerful interests to take over, such as landlords taking back formerly degraded land from tenants who had adopted more sustainable agriculture. In these contexts, it is rational for farmers to farm badly—at least they get to keep the land. The idea of sustainable agriculture may also appear to be keeping people in rural areas away from centres of power and 'modern' urban society, yet some rural people's aspirations may precisely to be to gain sufficient resources to leave rural areas. Agricultural sustainability also implies a limited role for agro-chemical companies, who would not be predicted to accept such losses of market lightly. It also suggests greater decentralisation of power to local communities and groups, combined with more local decision-making, both of which might be opposed by those who would benefit from corruption and non-transparency in private and public organisations. Research and extension agencies will have to change too, adopting more participatory approaches to work closely with farmers, and so must adopt different measures for evaluating job success and the means to promotion. Finally, social connectivity, relations of trust, and the emergence of significant movements may present a threat to existing power bases, who in turn may seek to undermine such locally based institutions.

Further tensions arise over the balance between whether food production is more sustainable if for local markets alone, or whether poorer farmers and communities should be encouraged to access international markets, but with the result that food causes greater transport externalities through long-distance travel. Moreover, farms with increased productivity export increasingly large amounts of nutrients to be eaten elsewhere, and it will be vital to ensure that replacement occurs at sustainable rates. There will be some who dispute this evidence of promising successes, believing that the poor and marginalised cannot possibly make these kinds of improvements. But we believe there is hope and leadership in this evidence of progress towards sustainability. What is quite clear is that these technologies and practices offer real opportunities for people to improve their food production whilst protecting and improving nature.

9. Scaling up through appropriate policies

Three things are now clear from this dataset about spreading agricultural sustainability:

(i) Some technologies and social processes for local scale adoption of more sustainable agricultural practices are well-tested and established.

(ii) The social and institutional conditions for spread are less well-known, but have been established in several contexts, leading to very rapid spread in the 1990s.
(iii) The political conditions for the emergence of supportive policies are least well-established, with only a very few examples of real progress.

As has been indicated earlier, agricultural sustainability can contribute to increased food production, as well as make an impact on rural people's welfare and livelihoods. Clearly much can be done with existing resources. A transition towards a more sustainable agriculture will not, however, happen without some external help and money. There are always transition costs in learning, in developing new or adapting old technologies, in learning to work together, and in breaking free from existing patterns of thought and practice. It also costs time and money to rebuild depleted natural and social capital.

Most agricultural sustainability improvements seen in the 1990s arose despite existing national and institutional policies, rather than because of them (Pretty, 1999; Pretty et al., 2001). Nonetheless, the 1990s have seen considerable global progress towards the recognition of the need for policies to support sustainable agriculture. Although almost every country would now say it supports the idea of agricultural sustainability, the evidence points towards only patchy reforms. Only two countries, Cuba and Switzerland, have given explicit national support for a transition towards sustainable agriculture—putting it at the centre of agricultural development policy and integrating policies accordingly. Cuba has a national policy for alternative agriculture and Switzerland has three tiers of support for practices contributing to agriculture and rural sustainability (Funes, 2001; Swiss Agency for Environment, Forests and Landscape, 1999; Swiss Agency for Environment, Forests and Landscape and Federal Office of Agriculture, 2000). Several countries have given sub-regional support, such as the states of Santa Caterina, Paraná and Rio Grande do Sul in southern Brazil supporting zero-tillage and catchment management, and some states in India supporting participatory watershed and irrigation management. A larger number have reformed parts of agricultural policies, such as China's support for integrated ecological demonstration villages, Kenya's catchment approach to soil conservation, Indonesia's ban on pesticides and programme for farmer field schools, Bolivia's regional integration of agricultural and rural policies, Sweden's support for organic agriculture, Burkina Faso's land policy, and Sri Lanka and the Philippines' stipulation that water users' groups manage irrigation systems (Pretty, 2002).

A good example of a carefully designed and 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 agro-ecological engineering, as the approach to achieve sustainability in agriculture. Pilot projects have been established in 2000 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, do illustrate what is possible when policy is appropriately coordinated (Li Wenhua, 2001).

An even larger set of countries has seen some progress on agricultural sustainability at project and programme level. However, progress on the ground still remains largely despite, rather than because of, explicit policy support. No agriculture minister is likely to say they are against sustainable agriculture, yet good words remain to be translated into comprehensive policy reforms. Agricultural systems can be economically, environmentally and socially sustainable, and contribute positively to local livelihoods. But without appropriate policy support, they are likely to remain at best localised in extent, and at worst simply wither away.

10. Conclusions

This empirical study shows that there have been promising advances in the adoption and spread of more sustainable agriculture. The 208 projects/initiatives show increases in food production over some 29 million hectares, with nearly 9 million households benefiting from increased food production and consumption. These increases are not yet making a significant mark on national statistics, as we believe there is a significant elasticity of food consumption in many poor rural households. They are eating the increased food produced, or marketing small surpluses to other local people. We cannot, therefore, yet say whether a transition to more sustainable agriculture, delivering increasing benefits at the scale occurring in these projects, will result in enough food to meet the current food needs of developing countries, the future basic needs after continued population growth, or the potential demand following adoption of more meat-rich diets. Even the substantial increases reported here may not be enough. There should be cautious optimism, as the evidence indicates that productivity can increase steadily over time if natural, social and human capital assets are accumulated.

Increased agricultural sustainability can also be complementary to improvements in rural people's livelihoods. It can deliver increases in food production at relatively low cost, plus contribute to other important functions. Were these approaches to be widely adopted, they would make a significant impact on rural people's livelihoods, as well as on local and regional food security. But there are clearly major constraints to overcome. There will be losers along with winners, and some of the losers are currently powerful players. And yet, social organisation and mobilisation in a number of contexts is already leading to new informal and formal alliances that are protecting existing progress and developing the conditions for greater spread. Improving agricultural sustainability clearly will not bring all the solutions, but promising progress has been made in recent years. With further explicit support, particularly through international, national and local policy reforms, these benefits to food security and attendant improvements to natural, social and human capital could spread to much larger numbers of farmers and rural people in the coming decades.

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