Sustainable intensification in African agriculture

Jules Pretty[1]*, Camilla Toulmin[2] and Stella Williams[3]

[1] University of Essex, Wivenhoe Park, Colchester, Essex, CO4 3SQ, UK
[2] International Institute for Environment and Development (IIED), 3 Endsleigh Street, London WC1H 0DD
[3] Iju Isaga, Agege, Lagos State, Nigeria

Over the past half-century, agricultural production gains have provided a platform for rural and urban economic growth worldwide. In African countries, however, agriculture has been widely assumed to have performed badly. Foresight commissioned analyses of 40 projects and programmes in 20 countries where sustainable intensification has been developed during the 1990s–2000s. The cases included crop improvements, agroforestry and soil conservation, conservation agriculture, integrated pest management, horticulture, livestock and fodder crops, aquaculture and novel policies and partnerships. By early 2010, these projects had documented benefits for 10.39 million farmers and their families and improvements on approximately 12.75 million ha. Food outputs by sustainable intensification have been multiplicative – by which yields per hectare have increased by combining the use of new and improved varieties and new agronomic–agroecological management (crop yields rose on average by 2.13-fold), and additive – by which diversification has resulted in the emergence of a range of new crops, livestock or fish that added to the existing staples or vegetables already being cultivated. The challenge is now to spread effective processes and lessons to many more millions of generally small farmers and pastoralists across the whole continent. These projects had seven common lessons for scaling up and spreading: (i) science and farmer inputs into technologies and practices that combine crops–animals with agroecological and agronomic management; (ii) creation of novel social infrastructure that builds trust among individuals and agencies; (iii) improvement of farmer knowledge and capacity through the use of farmer field schools and modern information and communication technologies; (iv) engagement with the private sector for supply of goods and services; (v) a focus on women's educational, microfinance and agricultural technology needs; (vi) ensuring the availability of microfinance and rural banking; and (vii) ensuring public sector support for agriculture. This research forms part of the UK Government's Foresight Global Food and Farming project.

Keywords: Africa; farming; scaling-up; social capital; sustainable intensification

The production challenge for Africa

Over the past half century, agricultural production gains across the world have helped millions of people to escape poverty, removed the threat of starvation and provided a platform for rural and urban economic growth in many countries. Between 1961 and 2007, world agricultural production almost tripled (Figure 1) while population grew from 3 to 6.8 billion. The green revolution drove this production growth with new varieties, inputs, water management and rural infrastructure. Most increases in food production were achieved on the same agricultural land, with net area only growing by 11 per cent over this period (data from FAO, 2009a).

In African countries, agriculture is widely seen to have performed worse than in Asia and Latin America. Production data per capita (of the total population) indicate that the amount of food grown on the continent per person rose slowly in the 1960s, then fell from the mid-1970s and has only just recovered to the 1960 level today (Figure 2). Over the same period, per capita food production increased by 102 per cent in Asia and 63 per cent in Latin America. This has helped to frame a prevailing international view that African agriculture has lagged behind the rest of the world. At the same time, there has been disinvestment in agricultural research, extension and production systems from both governments and international donors (DFID, 2009; Eicher, 2009; Haggblade and

*Corresponding author. Email: jpretty@essex.ac.uk

PAGES 5–24, doi:10.3763/ijas.2010.0583 ISSN: 1473-5903 (print), 1747-762X (online). www.earthscan.co.uk/journals/ijas

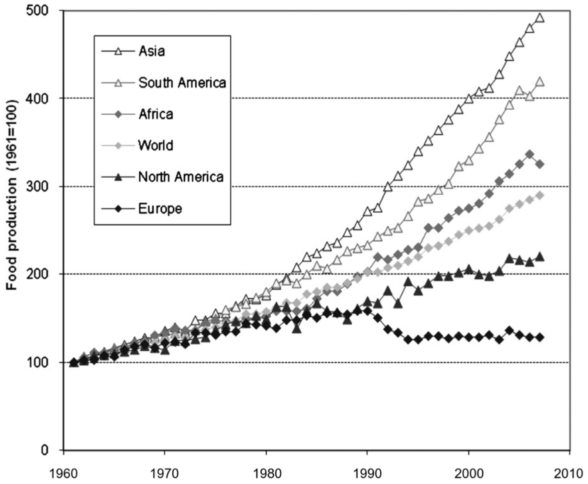

Figure 1 | Changes in net agricultural production (1961–2007)

Hazell, 2009). Yet agriculture still accounts for 65 per cent of full-time employment in Africa, 25–30 per cent of GDP and over half of total export earnings (IFPRI, 2004; World Bank, 2008). It underpins the livelihoods of over two-thirds of Africa's poor.

However, the net production data (net production is production minus seed required for the next harvest) show something different. These indicate that there has been substantial production growth across all regions of Africa, with output more than trebling (Figure 1) and growing faster than world output (mainly held back by the plateau in agricultural production in Europe). African agriculture has been called stagnant (e.g. Inter Academy Council, 2004), and a failure to achieve sustained productivity growth in smallholder agriculture has led to the temptation to embrace a singular large farm strategy (Collier and Dercon, 2009; Wiggins, 2009). Others, however, provide evidence for a dynamic and adaptive agricultural sector in many parts of Africa, over many years (Haggblade and Hazell, 2009; Röling, 2010).

All regions of Africa have seen net agricultural production growth, with the greatest increases in North and West Africa and the least in Middle and Southern regions (Figure 3). However, significant population growth has resulted in per capita production only rising in Middle and West Africa (by 34 and 10 per cent, respectively, since 1960). All other regions have seen dramatic falls in per capita food production: a 21 per cent fall in East Africa, 22 per cent in Southern Africa and 40 per cent in Middle Africa (Figure 4).

Thus, despite the improvements made in African agriculture, continued population growth means that the per capita availability of domestically grown food has not changed at the continent scale for 50 years and has fallen substantially in three regions. As a result, hunger and poverty remain widespread. Of the 1.02 billion people hungry in 2009–10, it is estimated that 265 million are in sub-Saharan Africa and 642 million in Asia and the Pacific (FAO, 2009b). For every 10 per cent increase in yields in Africa, it has been estimated that this leads to a 7 per cent reduction in poverty (more than the 5 per cent in Asia). Growth in manufacturing and service sectors has no such equivalent effect (World Bank, 2008; Wiggins and Slater, 2010). The 2008 World Development Report also noted that public spending on agriculture is lowest in the

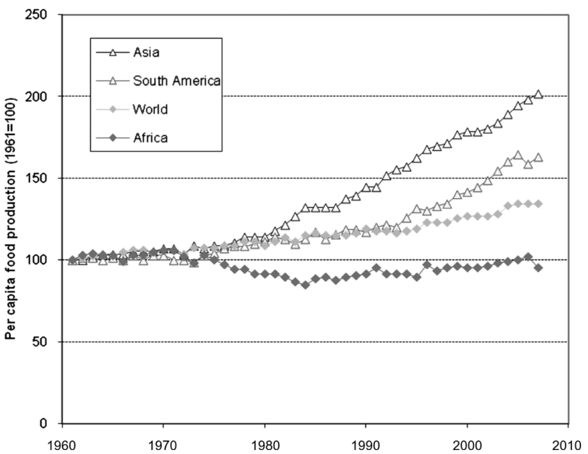

Figure 2 | Changes in per capita net agricultural production (1961–2007)

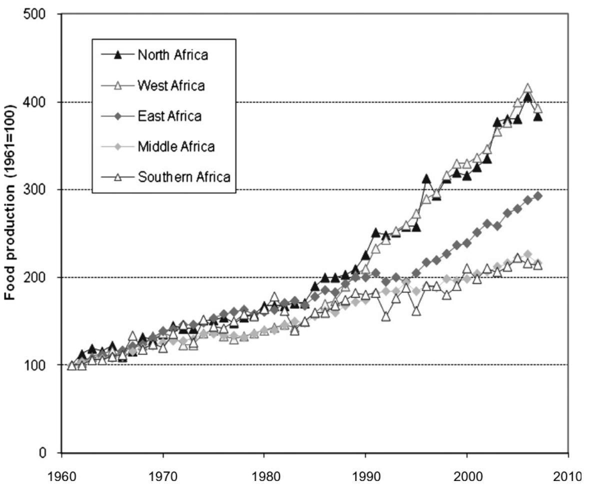

Figure 3 | Africa: changes in net agricultural production (1961–2007)

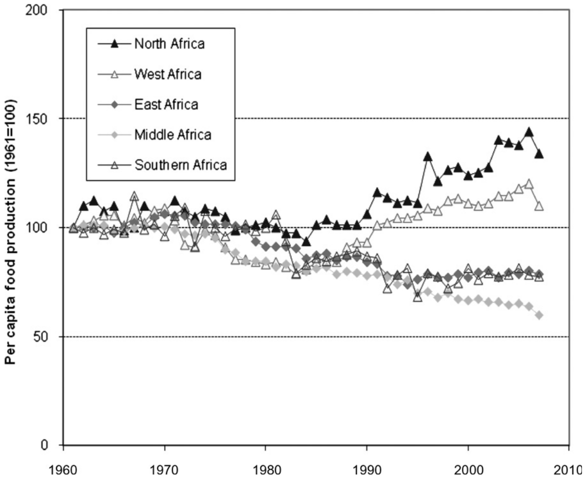

Figure 4 | Africa: changes in per capita net agricultural production (1961–2007)

very countries where the share of agriculture in GDP is highest.

It is also clear that conflicts have reduced agricultural production (Allouche, 2010). Food production in 13 war-affected countries of sub-Saharan Africa between 1970 and 1994 was 12 per cent lower in war years compared with peace-adjusted values. Over the period 1970–1997, FAO (2000) has estimated that conflict-related losses of agricultural outputs amounted to $121 billion ($4 billion per year).

Thus the challenge still remains substantial for African agriculture. Countries will have to find novel ways to boost crop and livestock production if they are not to become more reliant on imports and food aid. At the same time, an unprecedented combination of pressures is emerging to threaten the health of existing social and ecological systems (Pretty, 2008; Royal Society, 2009; Godfray *et al*., 2010). Across the world, continued population growth, rapidly changing consumption patterns, and the impacts of climate change and environmental degradation are driving the limited resources of food, energy, water and materials towards critical thresholds. These pressures are likely to be substantial across Africa (Reij and Smaling, 2008; DFID, 2009; Haggblade and Hazell, 2009; Toulmin, 2009; Wright, 2010).

The sustainable intensification of agriculture

All commentators now agree that food production worldwide will have to increase substantially in the coming years and decades (World Bank, 2008; IAASTD, 2009; Royal Society, 2009; Godfray *et al*., 2010; Lele *et al*., 2010). But there remain very different views about how this should best be achieved. Some still say agriculture will have to expand into new lands, but the competition for land from other human activities makes this an increasingly unlikely and costly solution, particularly if protecting biodiversity and the public goods provided by natural ecosystems (e.g. carbon storage in rainforest) is given higher priority (MEA, 2005). Others say that food production growth must come through redoubled efforts to repeat the approaches of the Green Revolution; or that agricultural systems should embrace only biotechnology or become solely organic. What is clear despite these differences is that more will need to be made of existing agricultural land. Agriculture will, in short, have to be intensified. Traditionally agricultural intensification has been defined in three different ways: increasing yields per hectare, increasing cropping intensity (i.e. two or more crops) per unit of land or other inputs (water), and changing land use from low-value crops or commodities to those that receive higher market prices.

It is now understood that agriculture can negatively affect the environment through overuse of natural resources as inputs or through their use as a sink for waste and pollution. Such effects are called negative externalities because they impose costs that are not reflected in market prices (Baumol and Oates, 1988; Dobbs and Pretty, 2004). What has also become clear in recent years is that the apparent success of some modern agricultural systems has masked significant negative externalities now becoming clear, with environmental and health problems documented and recently costed for many countries (Pingali and Roger, 1995; Norse *et al*., 2001; Tegtmeier and Duffy, 2004; Pretty *et al*., 2005; Sherwood *et al*., 2005). These environmental costs shift conclusions about which agricultural systems are the most efficient and suggest that alternative practices and systems that reduce negative externalities should be sought. This is what Giller has called the North–South divide between the ‘effluents of affluence’ and poverty caused by scarcity (Tittonell *et al*., 2009)

Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services (Pretty, 2008; Royal Society, 2009; Conway and Waage, 2010; Godfray *et al*., 2010).

A sustainable production system would thus exhibit most or all of the following attributes:

- utilizing crop varieties and livestock breeds with a high ratio of productivity to use of externally and internally derived inputs;
- avoiding the unnecessary use of external inputs;
- harnessing agro-ecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy, predation and parasitism;
- minimizing the use of technologies or practices that have adverse impacts on the environment and human health;
- making productive use of human capital in the form of knowledge and capacity to adapt and innovate and social capital to resolve common landscape-scale problems;
- quantifying and minimizing the impacts of system management on externalities such as greenhouse gas emissions, clean water availability, carbon sequestration, biodiversity and dispersal of pests, pathogens and weeds.

As both agricultural and environmental outcomes are pre-eminent under sustainable intensification, such sustainable agricultural systems cannot be defined by the acceptability of any particular technologies or practices (there are no blueprints). If a technology assists in efficient conversion of solar energy without adverse ecological consequences, then it is likely to contribute to the system's sustainability. Sustainable agricultural systems also contribute to the delivery and maintenance of a range of valued public goods, such as clean water, carbon sequestration, flood protection, groundwater recharge and landscape amenity value. By definition, sustainable agricultural systems are less vulnerable to shocks and stresses. In terms of technologies, therefore, productive and sustainable agricultural systems make the best of both crop varieties and livestock breeds and their agro-ecological and agronomic management.

The pioneering rice breeder Peter Jennings (2007), who led early advancements in high-yielding rice varieties during the first green revolution, has argued for an 'agro-nomic revolution':

> It is now widely recognized that rice yield gaps result from agronomic failings, and that future yield increases depend heavily on this science. Agronomy's time has come to lift farm productivity out of stagnancy.

Agronomy refers to the management of crops and livestock in their specific circumstances, and matches with the emergence of the term agro-ecology to indicate that there is a need to invest in science and practice which gives farmers a combination of the best possible seeds and breeds and their management in local ecological contexts.

This suggests that sustainable intensification will very often involve more complex mixes of domesticated plant and animal species and associated management techniques, requiring greater skills and knowledge by farmers. To increase production efficiently and sustainably, farmers need to understand under what conditions agricultural inputs (seeds, fertilizers and pesticides) can either complement or contradict biological processes and ecosystem services that inherently support agriculture (Royal Society, 2009; Settle and Hama Garba, 2011). In all cases, farmers need to see for themselves that added complexity and increased efforts can result in substantial net benefits to productivity, but they also need to be assured that increasing production actually leads to increases in income. Too many successful efforts in raising production yields have ended in failure when farmers were unable to market the increased outputs. Understanding how to access rural credit, or how to develop warehouse receipt systems and especially how to sell any increased output, becomes as important as learning how to maximize input efficiencies or build fertile soils. Equally, the creation of a social infrastructure of relations of trust, connections and norms is critical to effect and spread innovation.

Cases of sustainable intensification in Africa

Foresight[1] commissioned reviews and analyses from 40 existing projects and programmes from 20 countries of Africa where sustainable intensification has been developed, promoted or practised in the 2000s (some with antecedents in the 1990s). This was not a comprehensive analysis of all that is happening across Africa, nor was it a random sample. The intention was to investigate in detail the processes and outcomes on a sufficiently large enough area and across enough farms to draw some common conclusions about both how to develop productive and sustainable agricultural systems and how to scale these up to reach many more millions of people in the future. This analysis complements recent studies on successes in African agriculture that have shown compelling outcomes in rice varietal development (e.g. New Rices for Africa [NERICA]; Jones *et al*., 1997), soil and water conservation (Reij and Smaling, 2008), soyabean development (Giller, 2008), conservation agriculture (CA) (Kassam *et al*., 2009), cassava, hybrid maize, cotton, dairy and horticulture (Haggblade and Hazell, 2009), the Millions Fed report that focused also on IPM (integrated pest management) in cassava, regreening of the Sahel, cotton reforms, hybrid maize and IPM for cassava in Africa (Spielman and Pandya-Lorch, 2009), and the benefits of working with small farmers (Oxfam, 2009).

The cases commissioned here also had a range of different themes, comprising crop improvements, agroforestry and soil conservation, CA, integrated pest management, horticulture, livestock and fodder crops, aquaculture, and novel policies and partnerships (Table 1). By early 2010, these 40 projects had documented benefits for 10.39 million farmers and their families and improvements on approximately 12.75 million ha.

Table 1 | **Summary of types of projects commissioned**

Thematic focus	Number of project cases	Countries represented
Crop variety and system improvements	11	Ghana, Ethiopia, Kenya, Malawi, Mali, Mozambique, Tanzania, Uganda, Zimbabwe
Agroforestry and soil conservation	4	Burkina Faso, Cameroon, Malawi, Niger, Zambia
Conservation agriculture	4	Kenya, Lesotho, Tanzania, Zimbabwe
Integrated pest management	4	Benin, Burkina Faso, Kenya, Mali, Niger, Rwanda, Senegal, Uganda
Horticulture and very small-scale agriculture	3	Kenya, Tanzania
Livestock and fodder crops	4	Burkina Faso, Kenya, Mali, Rwanda, Tanzania, Uganda
Novel regional and national partnerships and policies	7	Benin, Cameroon, Congo, Cote d'Ivoire, Ghana, Kenya, Malawi, Nigeria
Aquaculture	3	Cameroon, Egypt, Ghana, Malawi, Nigeria
Total	40	

Note: The thematic focus is often only the starting point of a project or programme: many addressed multiple themes.

Food output and environmental improvements through sustainable intensification

Farmers have been able to increase food outputs by sustainable intensification in two ways. The first is multiplicative – by which yields per hectare have increased by combining the use of new and improved varieties with changes to agronomic–agro-ecological management. Across the 12.8 million ha in these projects, yields of crops rose on average by a factor of 2.13 (i.e. slightly more than doubled). The timescale for these improvements varied from 3 to 10 years. We estimate that this resulted in an increase in aggregate food production of 5.79 million tonnes per year, equivalent to 557kg per farming household (in all the projects). This does not include the additive benefits to yield production (as described in Table 2).

Many projects also improved food outputs by additive means – by which diversification of farms resulted in the emergence of a range of new crops, livestock or fish that added to the existing staples or vegetables already being cultivated. These new system enterprises or components included

- aquaculture for fish raising;
- small patches of land used for raised beds and vegetable cultivation;
- rehabilitation of formerly degraded land;
- fodder grasses and shrubs that provide food for livestock (and increase milk productivity);
- raising of chickens and zero-grazed sheep and goats;
- new crops or trees brought into rotations with staple (e.g. maize and sorghum) yields not affected, such as pigeonpea, soyabean and indigenous trees;
- adoption of short-maturing varieties (e.g. sweet potato and cassava) that permit the cultivation of two crops per year instead of one.

The environmental side effects or externalities have been shown to be highly positive in a number of cases. Carbon content of soils is improved where

Table 2 | **Summary of productivity outcomes from case studies**

Thematic focus	Area improved (ha)	Mean yield increase (ratio)	Net multiplicative annual increase in food production (thousand tonnes year^{-1})
Crop variety and system improvements	391,060	2.18	292
Agroforestry and soil conservation	3,385,000	1.96	747
Conservation agriculture	26,057	2.20	11
Integrated pest management	3,327,000	2.24	1,418
Horticulture and very small-scale agriculture	510	nd	nd
Livestock and fodder crops	303,025	nd	nd
Novel regional and national partnerships and policies	5,319,840	2.05	3,318
Aquaculture	523	nd	nd
Total	12,753,000	2.13	5,786

legumes and shrubs are used and where CA increases the return of organic residues to the soil. Legumes also help fix nitrogen in soils, thereby reducing the need for inorganic fertilizer on subsequent crops. In IPM-based projects, most have seen reductions in synthetic pesticide use (e.g. in cotton and vegetable cultivation in Mali, the pesticide used has fallen to an average of 0.25 litre ha^{-1} from 4.5 litre ha^{-1}; Settle and Hama Garba, 2011). In some cases, biological control agents have been introduced where pesticides were not being used at all (e.g. again in Mali, with the introduction of *Habrobracon hebetor* parasites to control millet head miner; Payne *et al*., 2011). The greater diversity of trees, crops (e.g. beans, fodder shrubs and grasses) and non-cropped habitats has generally helped to reduce run off and soil erosion, and thus increased the groundwater reserves.

A key constraint across Africa is nutrient supply. Many African soils are nutrient-poor, and fertilizer use is low across the continent compared with other regions. The average use of mineral fertilizers in sub-Saharan Africa does not surpass a very low value of 6–7kg of NPK ha^{-1}, against a middle and low income country average of nearly 100kg ha^{-1}, on land of generally low and declining inherent fertility (Reij and Smaling, 2008). As yields increase, the net export of nutrients also increases (unless nutrient cycles are closed). Thus, farms in many contexts will need to import or fix nutrients. Many approaches have been used in these projects, including inorganic fertilizers, organics, composts, legumes, and fertilizer trees and shrubs. The Malawi fertilizer subsidy programme is a rare example of a national policy that has led to substantial changes in farm use of fertilizers and the rapid shift of the country from food deficit to food exporter (Dorward and Chirwa, 2011).

Some new challenges have emerged, however, where successful enterprises need to establish a consistent supply of new inputs, such as in the aquaculture industry in Egypt, where feedstock is now imported to supply the rapidly growing sector.

A common objection made about many agronomic–agro-ecological approaches is their perceived need for increased labour (Tripp, 2005). However, this is highly site-specific. In some contexts, labour is highly limiting, especially where HIV/AIDS has removed a large proportion of the active population; in other contexts, there is plentiful labour available as there are few other employment opportunities in the economy. Successful projects of sustainable intensification by definition fit solutions to local needs and contexts, and thus take account of labour availability. In Kenya, for example, successful female owners of raised beds for vegetable production employ local people to work on the vegetable cultivation and marketing.

Labour for crop and livestock management is thus not necessarily a constraint on new technologies. In Burkina Faso, work groups of young men have emerged for soil conservation. Tassas and zai planting pits are best suited to landholdings where family labour is available, or where farm hands can be hired. The technique has spawned a network of young day labourers who have mastered this technique. Rather than migrating, they go from village to village to satisfy farmers' growing interest in improving their own lands. Owing to the success of land rehabilitation, farmers are increasingly buying degraded land for improvement, and paying these labourers to dig the zai pits and construct the rock walls and half-moon structures that can transform yields. This is one of the reasons why more than 3 million ha of land are now rehabilitated and productive.

Crop and agronomic–agro-ecological systems for improvement

The systems of improvement found in these projects comprise six main types of change: direct crop varietal development, integrated pest management, soil conservation and agroforestry, livestock management, new systems of management and making the most of small patches of land.

Crop varietal improvements

All cases showed that local research using and developing local plant and animal materials was highly effective. Crop varieties were developed by many different laboratory techniques, but in every case, participatory approaches to link with farmers were central (including participatory research, varietal testing and breeding). There was a strong focus on a range of so-called orphan crops – those missed or largely neglected by past breeding programmes and institutions. These include new varieties of cassava, plantain, orange-fleshed sweet potatoes, tef, pigeonpea and soyabean.

The improvement of orphan crops has benefited many poor families and communities, who had not been able to access better genetic material in the past. New constructs, such as orange sweet potato, have improved the health of people with vitamin A deficiency (affecting some 60 per cent of women and 28 per cent of children across Africa) (Mwanga and Ssemakula, 2011). In Uganda, CIP (International Potato Centre) with its NARO (National Agricultural Research Organization) partners have developed 19 new varieties of orange and non-orange sweet potatoes in the past 10 years, resulting in yields increasing from 4.4 to 10 $t\,ha^{-1}$. The range of plant material allows farmers to fit a variety to their own planting times, soil types and rainfall conditions. Orange-fleshed sweet potato is a good source of vitamin A, with some lines containing $>200\ \mu g\ g^{-1}$ β-carotene (Nestel *et al*., 2006; Zhao and Shewry, in press). In Mozambique, consumption of orange sweet potato has been shown to increase serum retinol concentrations in children substantially (Low *et al*., 2007). The cultivation of orange-fleshed sweet potato in Uganda has spread to 14,500 farmers on 11,000ha.

Tef is another classic neglected crop, especially as it is only grown in Ethiopia. It is grown on 8.5Mha, yet yields are only on average 1 $t\,ha^{-1}$. The Debre Zeit Agricultural Research Centre developed a new variety, *Quncho*, through participatory varietal selection, participatory plant breeding and on-farm seed multiplication and then worked with farmers' cooperatives, seed grower associations, and networks of processors and NGOs (Assefa *et al*., 2011). This infrastructure created effective conditions for extension of the *Quncho* variety, which was extended from 150 to 50,000ha over four years (to 2009). Yields have grown from 1 to 2.2 $t\,ha^{-1}$ even though farmers need to use no pesticides and only few herbicides.

Cassava is a major staple in many regions, yet it has been much neglected by agricultural research. But its productivity is threatened by the emergence of new disease problems, especially in Uganda where both cassava mosaic virus and brown streak virus have spread since the 1990s, resulting in declining yields. In Uganda, NAARI (Namulonge Agriculture and Animal Research Institute) (now NaCRRI (Namulonge Crop Resources Research Institute)) worked to produce locally developed resistant varieties, and introduced new agro-ecological management in the form of water troughs between rows. The new early maturing varieties can be harvested at between 6 and 12 months compared with 19 months for local varieties, which means more harvests are possible per unit of time. At the same time, yields have improved 5-fold to 15 $t\,ha^{-1}$. The research system working with NGOs focused also on added value by building processing centres where cassava is washed, peeled, chipped and packed into 1kg bags for sale. Farmers have become shareholders in these factories, and women have formed business groups to sell the cassava, thus increasing economic returns to rural areas.

Two novel legumes have also been introduced to good effect in East and Southern Africa: pigeonpea and soyabean (Jones and Silim, 2010; Giller *et al*., 2011). Pigeonpea had long been ignored by conventional plant breeders, yet by working with commercial seed companies, farmers' organizations and NGOs, ICRISAT (International Centre for Research in the Semi-Arid Tropics) has helped develop and introduce the world's first hybrid pigeonpea into five countries (Kenya, Malawi, Mozambique, Tanzania and Uganda). The medium duration crop allows two harvests per year (one if very dry), and farmers call it 'our coffee crop' – it is eaten and ready to sell in the seasons when vegetables are in short supply (thus supplying a source of cash income as coffee does). In Zimbabwe, 100,000 farmers have adopted soyabean into rotations following detailed research originating from the 1960s into rhizobial inoculum requirements (to ensure that nitrogen fixation occurs). The seeds are promoted with inoculum and fertilizers (P, K and S) through a Soyabean Promotion Task Force comprising universities, research, extension, farmers' groups and vegetable oil producers.

Integrated pest management

Pest management has centred on integrated approaches that seek to make the best of sound and novel science, to introduce new system components to provide pest management services and to limit the use of synthetic and harmful pesticides where possible (Williamson *et al*., 2008). All IPM programmes have aimed to build social and human capital through the widespread use of farmer field schools (FFSs) (in West Africa, for example, 3,500 FFSs have been held and these have trained 80,000 farmers). Farmers' learning of new techniques as well as new agroecological knowledge is also central to technology adaptation and adoption.

Good social networks generate collective action and adaptive management, in which the precise technological content is not specified beforehand. It is emergent from both the actors and agro-ecological circumstances. In Senegal, Mali, Burkina Faso and Benin, the spread of integrated plant and pest management (IPPM) through 3,500 FFSs has led to the adoption of many types of approaches to sustainable intensification, including pest management, development of seed beds, use of composting, marketing groups and expansion of new crops (mango, cowpea and sesame) (Settle and Hama Garba, 2011). In Mali, irrigated rice yields are up from 5.2 to 7.17t ha^{-1}, and in Senegal from 5.19 to 6.84t ha^{-1}. Seed use has fallen from 80 to 50kg ha^{-1}, compost use is up and pesticide use is down by 90 per cent. There has been a measurable effect on pesticide residues in surface waters. Such agricultural and environmental outcomes arise from the attention paid to developing bonding social capital among farmers with common interests, bridging social capital with markets and businesses, and linking social capital with multi-level institutions. Effective integrated pest management thus requires the development of both agro-ecological technologies and social capital.

In some cases, this has led to the redesign of agricultural systems. The best example comprises the use of legumes and grasses to attract and repel parasites and pests: for example, push–pull systems for maize in Kenya (Table 3). These systems have been adopted on 25,000 farms, and followed the initial scientific discovery of the role of semiochemicals released by plants and how they modified insect behaviour (Hassanali *et al*., 2008; Khan *et al*., 2011). It has been shown in the USA that genetic improvement of maize varieties has eliminated some naturally

Table 3 | **Push–pull integrated pest management in East Africa (Khan *et al*., 2011)**

Semiochemicals are compounds released by plants that modify the behaviour of insects (by acting like pheromones). The stemborer is a major pest of maize, and its rising incidence has coincided with the increasing cultivation of maize as a monoculture. Researchers at ICIPE (International Centre of Insect Physiology and Ecology) and Rothamsted found that (i) fodder and soil conservation grasses (e.g. Napier grass [*Pennisetum purpureum*] and Molasses grass [*Melinus minutifolia*]) attract stemborers to lay eggs on the grass rather than maize, (ii) legumes such as Desmodium act as repellents, driving the stemborers away. Desmodium also fixes up to 100kg N ha^{-1} year^{-1} and releases root allelochemicals that induce abortive germination of the parasitic weed, Striga. Napier grass also releases semiochemicals at a 100-fold greater rate in the first hour of nightfall, just as the stemborer moths seek host plants for oviposition: when the eggs hatch, 80% die as the Napier grass also produces a sticky sap that traps the larvae
Mixed systems were redesigned for farmers, with maize–legume intercrops surrounded by trap crops of grasses. The social infrastructure was redesigned to encourage engagement with farmers through field days, farmer field schools, farmer teachers, mass media and public meetings. Yields of maize have increased from 1 to 3.5t ha^{-1} and sorghum from 1 to 3t ha^{-1}. The number of farmers using push–pull has increased from a few hundreds to 25,000 in a decade (area 10,000ha). The target for 2015 is 50,000ha

occurring semiochemical traits. In earlier varieties, roots of maize attacked by corn rootworm emit volatile organic compounds (e.g. β-caryophyllene) that attract soil-dwelling nematodes to infect the pest. Restoration of this genetic capacity results in reduced root damage (Degenhardt *et al*., 2009; Lucas, 2010). This has been termed as influencing the 'signal landscape' of crop production systems.

Pearl millet head miner emerged as a major pest in Mali, Burkina Faso and Niger in the 1970s. With widespread pesticide control being not an economical option and plant breeding being unsuccessful over the years, biological control was explored as a possibility, with a natural enemy, the parasitic wasp (*H. hebetor*), eventually discovered in Senegal (Payne *et al*., 2011). Following a long period of testing, wasp rearing and release was begun in 2006. Parasitoid kit bags were given to farmers, each containing millet grain, 25 pest larvae and two pairs of *H. hebetor*. FFSs have been run for 700 farmers to increase their engagement and understanding of the approach, and in 2009 a total of 395 villages had become part of the programme, with 700,000 farmers benefiting from the presence of the parasitoid. Yields have been improved by 40 per cent, with kill rates of 72 per cent recorded for the pest larvae. The next phase of this GIMEM (Gestion Integrée de la mineuse de l'épi du mil [Integrated Management of Pearl Millet Head Miner]) project is targeting more releases, conducting more FFSs and aiming to cover 1 million ha of farmland with sustained presence of the parasitoid.

Soil conservation and agroforestry

Soil conservation on its own does not necessarily increase yields (the past focus has often been on avoiding future loss of soils), but conservation methods that capture water and add new system components (e.g. trees and livestock) can result in improved productivity of staples. Conservation is usually required across whole landscapes, and is thus a collective action challenge – farmers have to collaborate to make the best of the natural capital and environmental services that could be available. All effective soil conservation programmes now appreciate the need to focus on social capital formation as a prerequisite to widespread success. This is in contrast to past approaches that have tended to focus on coercion or incentives to adopt soil conservation (Pretty and Shah, 1997).

The West African Sahel has seen the most remarkable regreening and transformation, particularly in Burkina Faso and Niger (Reij and Smaling, 2008; Hassane, 2010; Sawadogo, 2011). Soil conservation and rainwater harvesting have used zai and tassas (improved traditional planting pits), contour bunds and half-moon structures to capture water and focus it on sorghum and millet. Trees have been added to the landscape as formerly barren and crusted lands were rehabilitated. Some 300,000ha of previously degraded land have been rehabilitated in Niger, and satellite photographs show how much the landscape has been transformed since the 1970s (Figure 5). In total, 3 million ha have been improved with soil conservation and the cultivation of 120 million new trees. In the mid-1980s, all farmers thought that trees belonged to the state and thus had no incentive to cultivate them. Now, with much greater decentralization of power and ownership rights, people are investing in trees, with densities reaching 20–50ha^{-1} (Figure 6). In one region, the average number of trees on the farms of adopters is 40, and seven for non-adopter farms. As a result, the time women spend on collecting fuelwood has fallen from 2.5h per day in the mid-1980s to an average of 0.5h per day today.

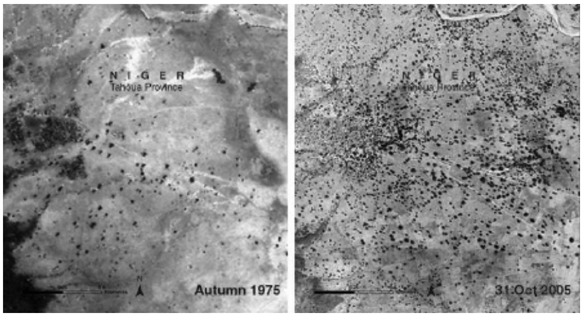

Figure 5 | Satellite photographs of Tahou province in Niger, showing increased tree cover
Credit: UNEP, 2008.

Figure 6 | A new agroforestry parkland in Niger's Zinder region (Kantché department). Dense stands of *Faidherbia albida* improve soil fertility
Credit: Hamado Sawadogo.

Some 80 per cent of women also now own livestock, as there is sufficient fodder. In parts of Burkina Faso, the water table has risen by 5m, indicating a positive environmental externality from the agricultural improvement. Ground cover and nitrogen fixation have further been improved through the adoption of cowpea and groundnut into rotations.

Agroforestry in Malawi, Tanzania, Mozambique, Zambia and Cameroon has shown how farmers can break continuous maize cultivation patterns with two years out of five devoted to fast-growing and N-fixing shrubs (e.g. Calliandra and Tephrosia). These soil-improving plants still result in an improvement in total maize production, with total maize production of 8 tonnes compared with 5 tonnes over the five-year period. On-farm testing and farmer involvement have been essential, as not growing maize for two years is counter intuitive to farmers. The approach has nonetheless led to the adoption of these 'fertilizer trees' (Asaah *et al*., 2011; Ajayi *et al*., 2011). There is a big contrast between past top-down systems and those followed here, which have focused on alley cropping, centred on close engagement with farmers through on-farm testing and adaptive participatory trials. As a result, many innovations in pruning, planting, plant mixtures and nursery operations have come from farmers themselves.

Livestock

Improvements to livestock systems have focused on better disease management, such as for *Trypanosomiasis* in West Africa, new locally developed breeds, such as of chickens in Uganda and cross-bred goats in Kenya, and the cultivation on-farm of new sources of fodder. Such fodder (perennial legumes, shrubs and grasses) has been carefully introduced into the typically small farms of East Africa in such a way that maize production has not been negatively affected, and now some 200,000 farmers cultivate new fodder crops.

Small livestock can be important sources of food and income for women and children, especially where labour is short due to HIV/AIDS incidence. This has been notable in the Rakai chicken project in Uganda, where an improved chicken based on local stocks was developed and extended to families alongside new management and housing methods (Roothaert *et al*., 2011). These included improved brooding, housing, feeding and parasite control, based largely on local methods and materials, and were thus adaptations from local practices. Many positive characteristics of the local poultry breed have been preserved in the new breed, with some value added through cross-breeding. Birds may hatch up to seven times per year compared with 2–3 times with unprogrammed birds; chicks are produced at lower cost since farmers do not need to transport them from distant towns, as was the case with commercial chicks.

In Mali and Burkina Faso, livestock and disease literacy have been improved so that herders can now identify both tsetse flies and their symptoms. More knowledge has led to the greater use of drug treatments, and a reduction in the incidence of *Trypanosomiasis* (Liebenehm *et al*., 2011).

Perhaps the greatest successes have been seen in the development and adoption of fodder shrubs in East Africa (Wambugu *et al*., 2011). Over the past two decades, research and development organizations collaborated in testing and validating selected fodder shrub species as reliable sources of less expensive and easily available protein feeds for improving milk production in smallholder farms in East Africa. Effective fodder species for smallholders include *Calliandra calothyrsus*, *Leucaena trichandra, Leucaena diversifolia, Chamaecytisus palmensis*, *Sesbania sesban*, *Morus alba* and *Gliricidia sepium.* Surveys on dissemination and adoption estimate that 205,000 smallholder dairy farmers (40–50 per cent being women) have planted fodder shrubs. Currently, fodder shrubs contribute about US$3.8 million annually to farmers' incomes across the region.

New systems of management

A number of new systems of management have been developed and extended to large numbers of farmers. Some of these were controversial at the beginning of programmes as they appear to break existing norms and rules for agriculture. The use of fertilizer shrubs and trees in maize rotations in Kenya, Malawi, Zambia and Rwanda, for example, has led to improved maize yields even though land is put under fertilizer fallows for two-year periods.

The development of CA has centred on abandoning ploughing or soil tillage in order to build up soil quality, nutrients and water. Such integrated soil management using CA methods can help to increase the carbon sink in soils. Soils contain twice as much carbon as the atmosphere. Historically, losses through cultivation and disturbance have been established to be 40–80 Pg (Petagrams) C (Smith, 2008; Kilham, 2010), and losses continue at a rate of 1.6 ± 0.8 Pg C per year, mainly in the tropics.

There is thus considerable scope to reduce emissions and increase the capacity of agricultural soils as a sink. Agricultural systems that result in increased carbon sequestration are also more sustainable. They contribute to farmers' incomes through natural capital accumulation on the farm, and they result in fewer negative externalities. Soil biodiversity is also higher, including both microorganisms and macrofauna. Moreover, sustainable systems are more energy efficient, particularly because of their lower reliance on purchased inputs that are energy-expensive to manufacture.

CA has been practised for three decades and has spread widely from its origins in Latin America. It has been estimated that there are now some 106 million ha of arable and permanent crops grown without tillage in CA systems (primarily in Argentina, Brazil and North America), corresponding to an annual rate of increase globally since 1990 of 5.3 million ha (Kassam *et al*., 2009). Wherever CA has been adopted it appears to have had both agricultural and environmental benefits, as shown in Table 4. CA has now spread to some 25,000ha in Lesotho, Kenya, Tanzania and Zimbabwe, and resulted in increased and more stable yields (Marongwe *et al*., 2011; Owenya *et al*., 2011). In Zimbabwe, 8,000 farmers have adopted CA methods, resulting in maize yields growing by 67 per cent. In Lesotho, the numbers are smaller (5,000 farmers), but the productivity increases are vital for the very small farms (Silici *et al*., 2011).

In Mali, the system of rice intensification (SRI) has been extended to some 400 farmers (Styger *et al*., 2011). SRI originated in Madagascar and has spread to several hundreds of thousands of farmers in Asia and Africa. It breaks several well-established rules for irrigated rice management: farmers transplant single, very young (4–6 days), widely spaced seedlings, rather than closely spaced clumps of plants, thus greatly reducing plant populations with substantial seed saving. SRI also replaces the traditional practice of continuous flooding of paddy fields with limited and intermittent water applications – this in turn saves water and makes rice production possible where there is not enough water to keep fields inundated. Yields have so improved from these systems that many rice research organizations have not yet been able to believe the evidence, since it runs counter to assumptions.

Table 4 | **Elements of CA (from Kassam *et al*., 2009)**

The main components of CA are:

- maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop
- minimizing soil disturbance from tillage and thus seeding directly into untilled soil, eliminating tillage altogether once the soil has been brought to good condition, and keeping soil disturbance from cultural operations to the minimum possible
- diversifying crop rotations, sequences and associations, adapted to local environmental conditions, and including appropriate nitrogen-fixing legumes; such rotations contribute to maintaining biodiversity above and in the soil, contribute nitrogen to the soil/plant system, and help avoid build-up of pest populations

Making the most of patches

The final systems for improvement examined here centre on the intensive use of small patches of land. As these often do not appear in the normal boundaries of fields, they have often been ignored by agricultural research and extension. The main approach has centred on the use of raised beds, which after labour-intensive construction result in better water-holding capacity and higher organic matter. These beds can be highly productive and diverse, and are able to sustain vegetable growth during dry seasons when vegetables in markets are in short supply. The greatest use of organic methods has occurred through the spread of raised beds (e.g. to 150,000 farmers in Kenya).

One FarmAfrica project in Kenya and Tanzania is focusing on the revival and extension of indigenous vegetables on small beds (Muhanji *et al*., 2011). With 500 small farmers organized into 20 groups, and on average 20 beds cultivated per farmer (0.05–0.1ha), farmers have been able to obtain greater returns from markets as well as use 50 per cent less fertilizer and 30 per cent less pesticide than for conventionally grown vegetables. The indigenous and exotic vegetables include amaranths, cowpeas, nightshades, spinach, kales and cabbage. The innovative approaches used by the project included (i) training of trainers and support to business groups; (ii) information about production, utilization and marketing; (iii) changes in the production of indigenous vegetables; (iv) seed dissemination, distribution and multiplication; and (v) increased market orientation through business support units. Individual growers can obtain 5–8 harvests of amaranth and nightshade per year, with an annual income created of some $3,000–4,500.

Aquaculture is a further form of patch management. Two types have emerged: integrated on farms through the construction of farm ponds and on small plots or tanks in peri-urban settings (Brummet and Jamu, 2011; Miller and Atanda, 2011). The latter have led to the emergence of many new businesses and changes in local eating behaviour. In Malawi and Zambia, the 13,400 small-scale aquaculture systems (mean size 275m^2 per farm) produce approximately 40kg of fish per year. In Cameroon, a number of small operations have increased to commercial scale, each with an average of 11,500m^2 of fish pond. In Nigeria, fish ponds and tanks in the peri-urban environment have become popular and successful, with some 3,000 fish farms now established in the past 10 years. Market demand for fish is high, and this is partly driving the emergence of small businesses raising catfish and tilapia. In a concrete pond using improved feed and management techniques, catfish productivity is 50–100t ha^{-1} year^{-1}. Wastes from tank systems are recycled back to the soils of integrated gardens. There is considerable room for growth in this sector, with locally raised fish replacing imports as an important protein component in the diet.

New forms of social infrastructure

Social capital is used as a term to describe the importance of social relationships in cultural and economic life. The term includes such concepts as the trust and solidarity that exist between people who work in groups and networks, and the use of reciprocity and exchange to build relationships in order to achieve collective and mutually beneficial outcomes. Norms of behaviour, coupled to sanctions, help to shape the behaviour of individuals, thereby encouraging collective action and cooperation for the common good.

The term 'social capital' captures the idea that social bonds and norms are important for people and communities. It emerged as a term after detailed analyses of the effects of social cohesion on regional incomes, civil society and life expectancy. As social capital lowers the transaction costs of working together, it facilitates cooperation. People have the confidence to invest in collective activities, knowing that others will also do so. They are also less likely to engage in unfettered private actions with negative outcomes, such as resource degradation. Collective resource management programmes that seek to build trust, develop new norms and help form groups have become increasingly common, and such programmes are variously described by the terms community-, participatory-, joint-, decentralized- and co-management.

Social capital is thus seen as an important prerequisite to the adoption of sustainable behaviours and technologies over large areas. Three types of social capital are commonly identified (Hall and Pretty, 2008). These are the ability to work positively with those closest to us who share similar values (referred to as bonding social capital). Working effectively with those who have dissimilar values and goals is called bridging social capital. Finally, the ability to engage positively with those in authority either to influence their policies or to garner resources is termed linking social capital (Woolcock, 1998, 2001; Pretty, 2003). Linking social capital encompasses the skills, confidence and relationships that farmers employ to create and sustain rewarding relationships with staff from government agencies. To gain the most from social capital, individuals and communities require a balanced mixture of bonding, bridging and linking relationships.

Where social capital is high in formalized groups, people have the confidence to invest in collective activities, knowing that others will do so too. Farmer participation in technology development and

Table 5 | **Knowledge and information needs and sources for farmers**

Knowledge and information needs	**Sources of information**
1. Information on systems that sustain food production 2. Information on current and new technology, and its performance in real farm settings 3. Business management advice 4. Information on markets, including an ability to investigate market opportunities 5. Information on domestic policy and regulation, including what producers need to do in order to comply 6. Regular and timely information on prices	1. Informal communication and exchange 2. Individual innovators 3. Non-state organizations (e.g. farmers associations, scientific societies, universities and colleges) 4. Commercial enterprises 5. The state (e.g. research and extension, tax authorities)

Source: Garforth (2010).

participatory extension approaches has emerged as a response to such new thinking. New approaches such as FFSs and the agricultural knowledge and information system have been developed that emphasize the development of both social and human capital. As has been indicated above, direct farm level links between researchers, extensionists and farmers are a prerequisite for technology innovation and adaptation. The knowledge and information needs of farmers and their sources are shown in Table 5.

Almost all the 40 projects analysed are engaged in the development and formation of new forms of social capital, which when connected together has resulted in the emergence of a new social infrastructure in rural areas. In the past, extension systems were seen as the tool to link research outcomes to farmers. However, support for monolithic structures has declined, partly as a result of the limited success of transfer-of-technology styles of information flow (Anderson, 2008). Extension systems have been closed or underfunded, and thus many countries lack the institutions that can connect farmers with external agencies and markets. As a result, new forms of social infrastructure have emerged to build bonding, bridging and linking social capital. If trust between actors is good, then transformations in production systems are possible. New forms of farmer-based social infrastructure include FFSs, cooperatives, rural resource centres, business groups, common interest groups (CIGs), micro-credit groups and catchment groups. Many of these help to build farmers' knowledge on particular areas, such as on pests and diseases, or plucking intensity in tea. Farmers learn best when they are encouraged to experiment; researchers learn best when they work in a participatory way with farmers to ensure that plant materials and animals are suited to local needs and norms (e.g. through participatory plant breeding).

Farmer involvement in all stages of the innovation process is critical, as novel technologies and practices can be learned directly and then adapted to particular agro-ecological, social and economic circumstances. This is particularly important where a sustainable intensification practice or technology appears to break existing norms for farmers, such as introducing fodder shrubs into maize systems, grasses and legumes for pest management, early transplanting and wide-spacing of rice, and adoption of CA that involves multiple innovations to replace ploughing. Farmer participatory research, on-farm testing and farmer selection of plant materials have all been

Table 6 | **The principal elements of FFSs**

- Each FFS consists of a group of approximately 25 farmers, working in small subgroups of about five each. The training is field-based and season-long, usually meeting once per week
- The season starts and ends with a 'ballot box' pretest and post-test, respectively, to assess trainees' progress
- Each FFS has one training field, divided into two parts: one IPPM-managed (management decisions decided on by the group, not a fixed 'formula'), and the other with a conventional treatment regime, either as recommended by the agricultural extension service or through consensus of what farmers feel to be the 'usual' practice for their area
- In the mornings, the trainees go into the field in groups of five to observe and make careful observations on growing stage and condition of crop plants, weather, pests and beneficial insects, diseases, soil and water conditions. Interesting specimens are collected, put into plastic bags and brought back for identification and further observation
- On returning from the field to the meeting site (usually near the field, under a tree or other shelter), drawings are made of the crop plant which depict plant condition, pests and natural enemies weeds, water, and anything else worth noting. A conclusion about the status of the crop and possible management interventions is drawn by each subgroup and written down under the drawing (agro-ecosystem analysis)
- Each subgroup presents its results and conclusions for discussion to the entire group. In these discussions, as well as in the preceding field observations, the trainers remain as much as possible in the background, avoiding all lecturing, not answering questions directly, but stimulating farmers to think for themselves
- Special subjects are introduced throughout the training. These include maintenance of 'insect zoos' where observations are made on introduced pests, beneficial insects, and their interactions. Other classic special subjects include leaf removal experiments to assess pest compensatory abilities, life cycles of pests and diseases, etc. (in recent years with expansion of the topics away from just IPM)
- Socio-dynamic exercises serve to strengthen group bonding and active trainees are encouraged in the interest of post-FFS farmer-to-farmer dissemination

Source: Settle and Hama Garba (2011).

embedded in a number of institutions. The key principles of FFSs are shown in Table 6.

Linking social capital is built through multi-agency partnerships involving NGOs, CSOs (Community Service Organizations), research organizations, farmer organizations, businesses, banks and government policy-making institutions. The particular mix cannot be prescribed for all circumstances – but some mix is important. In all successes, farmers have been organized into some new form of social structure (e.g. FFSs, business groups, producer cooperatives, CIGs, microfinance groups and nursery management), which is then linked outwards and upwards to other organizations. The investment in social capital takes time to build, but once established appears to be an essential condition for rapid information flow and growth of trust.

Linking research into social infrastructure is crucial to successful outcomes, as the Pan African Bean Research Alliance (PABRA) has shown (Buruchara *et al*., 2010). In the 1990s, root rot began to cause regular bean crop failures across Rwanda, Kenya and Uganda. Through participatory technology development, the use of marker-assisted breeding for new varieties, farmer-to-farmer exchanges, engagement with NGOs and media, integrated disease management has seen locally developed and resistant varieties spread to hundreds of thousands of farmers. Integrated approaches also involve the use of farmyard manure, other legumes as green manures (e.g. mucuna), fertilizers and raised beds alongside the improved genetic material. Beans are now available throughout the year to eat.

In East Africa, the successful spread of fodder shrub cultivation to 200,000 farmers has been achieved with a focus on farmer-to-farmer processes, involvement of many NGOs, training a cohort of dissemination facilitators, a focus on seed companies, civil society campaigns and, above all, a focus on women farmers (Wambugu *et al*., 2011). Through this programme, it is estimated that $4 million have been added to farmer incomes per year.

Innovative co-learning and extension platforms have been created through the use of videos. In West Africa (Nigeria, Benin, Ghana, Gambia and Guinea), video has been particularly successful in raising awareness among farmers of potentially beneficial technologies and practices (Van Mele, 2010: Bentley and Van Mele, 2011). Researchers from AfricaRice have found that farmers are not particularly concerned if videos show farmers in very different cultural contexts (e.g. Bangladesh) – the key question is whether they recognize the crops and type of landscape as being relevant to their own. The process involves identification of topic, direct learning about the context, development of the video with local actors, testing in various contexts and then scaling up and out. Examples that have spread include planting sticks, rice parboiling, seed health testing in water and techniques for capturing grasscutter rats.

Mobile phones are also helping farmers link to one another and also to obtain early information from markets. The revolution in information and communication technologies (ICTs) and information management systems is radically opening up access to external knowledge among even the poorest. The rate of growth of mobile phone technology is particularly striking. In 2009, mobile cellular penetration in all developing countries exceeded 50 per cent, reaching 57 per 100 inhabitants, up from 23 per cent in 2005. Together with the spread of internet access, this means agricultural and price information can be increasingly sourced from distant locations.

Emergent private sectors

Many of the projects have shown the importance of engagement with the private sector. Farmers are also entrepreneurs and business people, but are rarely thought of in this way. Yet they wish to produce enough food or fibre to eat and sell, so that they can make money too. Some projects have shown the emergence of farmers as new entrepreneurs. In Uganda, women have organized into groups to process and sell cassava. In Nigeria, aquaculture entrepreneurs have emerged to focus just on raising and selling fish, and others for producing and selling feed. In Kenya, the extension system focuses on forming farmers into CIGs for business activities. Other projects have realized that the existing private sector is itself a route to farmers. Seed suppliers, for example, have been crucial in getting fertilizer tree seeds to farmers in southern Africa.

Novel partnerships (a form of social capital) have also been designed, such as between the private sector, NGOs, public sector, CSOs, farmers and banks. These help to create trust. In some cases, existing private actors have engaged with farmers and the public sector in new ways, such as Liptons (Unilever) with smallholder tea growers in Kenya through FFSs (Mitei, 2011). Liptons purchases tea from 500,000 smallholder tea growers, and uses FFSs with 720 farmers in four regions to work on developing practices that would lead to better yields. It was known that GAP (good agricultural practice) recommendations, however worthy, were generally not adopted by farmers. However, the FFSs improved links between Liptons, Kenya Tea Development Authority and farmers, and as trust developed so new techniques and innovations spread, including on plucking technique and frequency, fertilizer use and planting of native trees on farms. These farmers have seen a 19 per cent increase in yields.

In Ghana, the Ghana Grains Partnership has brought together funders (an enterprise fund), banks, a fertilizer company, NGOs, local buyers and traders and farmer groups to ensure that farmers have access to seeds and inputs (Guyver and MacCarthy, 2011). The three key interventions have been the twinning of commercial and non-commercial objectives, a focus on the whole agriculture value chain (including inputs and finance), and an open and well-informed dialogue with farmers' associations, commercial rural enterprises and other elements of the private sector. By 2010, 5,000 farmers were part of the project and maize yield had increased from 1 to 3t ha^{-1}. The target for 2012 is 25,000 farmers on 30–40,000ha.

The success of the spread of indigenous vegetable cultivation (such as African nightshade, okra, amaranths, spider plant and eggplants) on raised beds in Kenya and Tanzania has been because of a focus on both crop management and markets where consumer demand for vegetables is high (Muhanji *et al.*, 2011). The several hundred farmers involved in vegetable cultivation have tripled their area of cultivation in response to sales and demand.

Enabling policy environments

In addition to the right technologies (seeds and breeds and their agronomic–agro-ecological management) and social infrastructure, ideally policy environments would be supportive of sustainable intensification and its requirements. In most cases, however, agricultural policy or domestic or international policy has been generally unhelpful rather than enabling. Many successes have emerged despite policy rather than because of policy. The exceptions, however, show that activities can be greatly scaled up with the appropriate policy support.

In Kenya, the National Agricultural and Livestock Extension Programme is built on 20 years of support to extension (mainly from Sida), and reaches 500,000 farmers per year. Its early experience of building up 4,500 catchment groups for soil conservation has now been extended to working with 7,000 CIGs each year that emerge from local needs and opportunities (Kiara, 2011). Many new private enterprises have been formed with the help of government as part of a unique social infrastructure comprising stakeholder forums, implementation teams, focal area development committees and CIGs. All these help to develop ownership in both ways of working and spread of technologies. Some 70 per cent of participating farmers say they now regard farming as a business. In this way, public money is being used to build social capital that, in turn, is creating increased productivity of agriculture.

The CARBAP (African Research Centre on Banana and Plantain) is a good example of a regional research partnership for plantains and bananas across Cameroon, Congo, Cote d'Ivoire, Ghana and Nigeria (Tomekpe and Ganry, 2011). It links researchers, creates novel platforms, undertakes training and disseminates materials. It encourages mass propagation by farmers – after PIF (Plants Issus de Fragments) training, some 10 million new disease-resistant plants were spread to farms in two years.

In Malawi, the fertilizer subsidy programme has been so successful in terms of farmer take-up that net imports of maize have fallen from 132,000 tonnes at the start of the programme in 2005–06 to 1,000 tonnes in 2008–09 (Dorward and Chirwa, 2011). The net extra production of maize per hectare has been between 406,000 and 866,000t $year^{-1}$. Some 67 per cent of farmers in 2008–09 benefited from the receipt of fertilizer coupons (estimated 1.7–2.5 million farmers). The policy is controversial for some, who argue that the money could have been spent differently, that the subsidy is too great a proportion of GDP (now 6.6 per cent) or even that farmers should not have been subsidized (even though OECD (Organisation for Economic Co-operation and Development) countries routinely subsidize their farmers). Yet poor households have seen increases in income of 10–100 per cent (some 60 per cent of maize producers are also buyers of maize, and thus high prices hurt them). In Malawi, there are also 345 fertilizer fallows groups, who have extended practices to some 300,000ha.

In Mali, producer cooperatives for cotton production are now a national priority, and 7,200 have been formed since 2005. In the Oxfam project, organic, conventional and fair-trade cotton cooperatives have led to increased yields, better prices and the adoption of a range of sustainable intensification technologies. Women have particularly benefited from a clear focus on improving their organization and roles on farms (Traore and Bickersteth, 2011).

It is clear that incentives are often needed to help establish and embed novel social and technical infrastructure, so that farmers are able to adopt new practice. The World Food Programme has used food aid to encourage farmers to adopt CA in certain circumstances. In West Africa, aid support has been used to subsidize the initial cultivation of stone bunds and the establishment of nurseries for trees. In other contexts, aid has been used to subsidize FFSs. In the Malawi case above, the nation has spent very large sums on fertilizer subsidies. In every case, there are critics who argue that such external support makes the activity itself inefficient and unlikely to be sustained. The alternative view is that if the subsidy is used to create a new form of social, human or natural capital that will yield benefits over time, or builds capacity in such a way that systems are permanently transformed, then this is an efficient use of public money.

Governments can take further actions to value their own agricultural systems. On average, African countries spend 4–5 per cent of national budgets on agriculture, compared with 8–14 per cent in Asia (Fan *et al*., 2008), even though African leaders in 2003 called for a 10 per cent budget allocation to agriculture by 2008–09. In Ghana, when government increased the proportion of the FOB price of cocoa paid to farmers from 40 to 70 per cent, farmers responded by doubling production, showing what smallholders are capable of achieving when given the appropriate support (Röling, 2010).

Scaling up and spread

The projects analysed in this study have resulted in more than 10 million farmers adopting a wide variety of approaches and technologies for sustainable intensification of their agricultural systems. As a result, food production has increased substantially. However, the challenge is now to spread effective processes and lessons to many more millions of generally small farmers and pastoralists across the whole of the continent (World Bank, 2008; DFID, 2009; Oxfam, 2009). These 40 projects had seven common lessons for scaling up and spreading (Table 7).

The core elements for each of these seven requirements are as follows:

Table 7 | **Seven requirements for scaling up sustainable intensification**

1. Scientific and farmer input into technologies and practices that combine crops–animals with appropriate agro-ecological and agronomic management
2. Creation of novel social infrastructure that results in both flows of information and builds trust among individuals and agencies
3. Improvement of farmer knowledge and capacity through the use of FFSs, farmer trainers, videos and modern ICTs
4. Engagement with the private sector to supply goods and services (e.g. veterinary services, manufacturers of implements, seed multipliers, milk and tea collectors) and development of farmers' capacity to add value through their own business development
5. A focus particularly on women's educational, microfinance and agricultural technology needs and building of their unique forms of social capital
6. Ensuring that microfinance and rural banking are available to farmers' groups (for both consumption and production purposes)
7. Ensure public sector support to lever up the necessary public goods for sustainable intensification of agriculture in the form of innovative and capable research systems, dense social infrastructure, appropriate economic incentives (subsidies, price signals), legal status for land ownership and improved access to markets, through transport infrastructure

1. Science and farmer inputs into technologies and practices that combine crops–animals with their agro-ecological and agronomic management:
   - the best of modern laboratory science combined with the best of field science;
   - the use of participatory and interactive methods to engage farmers and improve research outputs;
   - sustainable intensification works to increase yields and improve environmental services;
   - adaptive testing is essential as there is large heterogeneity of soil types and agro-ecologies across Africa.
2. Create novel infrastructure that results in both flows of information and builds trust among individuals and agencies:
   - farmers organized into groups both to share and increase economies of scale through collective action;
   - farmers linked with other local actors (businesses, banks and NGOs);
   - research linked with NGOs, private sector, farmers and extension systems;

- higher-level platforms, partnerships and joint governance.

3. Improvement of farmer knowledge and capacity through the use of FFSs, farmer trainers, videos and modern ICTs:
   - farmers do not know everything required – although they do have many practices and technologies of value to research systems and other farmers;
   - pest, disease, market and climate conditions are constantly changing, and farmers may not know of new threats or opportunities;
   - farmer engagement and knowledge are essential for the adaptation of innovations to local circumstances and over time;
   - many technologies represent very new concepts to farmers (and often to other agricultural actors, who will need training too);
   - use mass media and ICTs to create awareness of technologies (although rarely sufficient alone to encourage adoption).
4. Engage with the private sector to supply goods and services (e.g. veterinary services, manufacturers of implements, seed multipliers, and milk and tea collectors) and develop farmers' capacity to add value through crop processing and broader business development:
   - farmers wish to make money, not just produce food;
   - the private sector is a source of innovation and sustained capacity (especially in seed systems);
   - farmers' cooperatives and societies are important.
5. Focus particularly on women's educational, microfinance and agricultural technology needs, and build their unique forms of social capital:
   - women are under represented in research and governance systems;
   - women are the primary farmers in many contexts;
   - women are routinely ignored by external agencies.
6. Ensure that microfinance and rural banking are available to farmer groups (for both consumption and production purposes):
   - farm families often need very small amounts of finance, yet are denied them from conventional banks;
   - lending to groups is low risk as it results in high repayment rates.
7. Ensure public sector support to lever up the necessary public goods for sustainable intensification of agriculture in the form of innovative and capable research systems, dense social infrastructure, appropriate economic incentives (subsidies, price signals), legal status for land ownership and improved access to markets through transport infrastructure:

   - governments and international agencies should recognize that agricultural improvements result in reductions in poverty and hunger;
   - investments in agriculture pay off economically, socially and politically;
   - governments invest too little in agriculture and recognize too little the value of their own smallholders.

Conclusions

These projects of sustainable intensification drawn from across Africa show that if there is a political and economic domestic recognition that 'agriculture matters', then food outputs can be increased not only without harm to the environment but also in many cases to increase the flow of beneficial environmental services. Such improvements then contribute to national domestic food budgets, foster new social infrastructure and cultural relations, help the emergence of new businesses and so drive local economic growth, and ultimately improve the well-being of both rural and urban populations.

These projects contained many different technologies and practices, yet had similar approaches to working with farmers, involving agricultural research, building social infrastructure, working in novel partnerships and developing new private sectors options. Only in some of the cases were national policies directly influential (although clearly national policy environments affected outcomes).

The 40 projects involved significant benefits for more than 10 million farmers and their families across 20 countries. The challenge now is to find ways of scaling up the processes used in these projects so that tens and eventually hundreds of millions of people benefit. These projects indicated that there were seven key requirements for such scaling up of sustainable intensification:

1. Scientific and farmer input into technologies and practices that combine crops–animals with appropriate agro-ecological and agronomic management.

2. Creation of novel social infrastructure that results in both flows of information and builds trust among individuals and agencies.
3. Improvement of farmer knowledge and capacity through the use of FFSs, farmer trainers, videos and modern ICTs.
4. Engagement with the private sector to supply goods and services (e.g. veterinary services, manufacturers of implements, seed multipliers, and milk and tea collectors) and development of farmers' capacity to add value through their own business development.
5. A focus particularly on women's educational, microfinance and agricultural technology needs, and building of their unique forms of social capital.
6. Ensuring that microfinance and rural banking are available to farmers' groups (for both consumption and production purposes).
7. Ensure public sector support to lever up the necessary public goods for sustainable intensification of agriculture in the form of innovative and capable research systems, dense social infrastructure, appropriate economic incentives (subsidies and price signals), legal status for land ownership and improved access to markets through transport infrastructure.

Acknowledgements

The authors are grateful to the following for their helpful comments on earlier versions of this paper: Ken Giller, Charles Godfray, Ralph von Kaufmann, Nick Nisbett, Jon Parke, Frank Place, Mike Segal, Sandy Thomas and Alan Tollervey. The analysis benefited greatly from the insights and observations of authors of the individual case studies commissioned for the UK government's Foresight Global Food and Farming Futures project, and from the discussions at a workshop held in Ouagadougou, Burkina Faso, in July 2010.

Note

1. UK Government Office of Science Foresight project: Global Food and Farming.

References

Ajayi, O. C., Place, F., Akinnifesi, F. K., Sileshi, G. W., 2011, 'Fertilizer tree systems in Southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe)', *International Journal of Agricultural Sustainability* 9(1), 129–136.
Allouche, J., 2010, 'Water and food systems in relation to political stability, migration and equality', *Food Policy* (in press).
Anderson, J. R., 2008, *Aligning Global Agricultural Research Investments with National Development Activities: The CGIAR Experience*, CGIAR Secretariat, Washington, DC.
Asaah, E. K., Tchoundjeu, Z., Leakey, R. R. B., Takousting, B., Njong, J., Edang, I., 2011, 'Trees, agroforestry and multifunctional agriculture in Cameroon', *International Journal of Agricultural Sustainability* 9(1), 110–119.
Assefa, K., Aliye, S., Belay, G., Metaferia, G., Tefera, H., Sorrells, M., 2011, '*Quncho*: the first most popular tef variety in Ethiopia', *International Journal of Agricultural Sustainability* 9(1), 25–34.
Baumol, W. J., Oates, W. E., 1988, *The Theory of Environmental Policy*, Cambridge University Press, Cambridge.
Bentley, J., Van Mele, P., 2011, 'Sharing ideas between cultures', *International Journal of Agricultural Sustainability* 9(1), 258–263.
Brummett, R. E., Jamu, D. M., 2011, 'From researcher to farmer: partnerships in integrated aquaculture-agriculture systems in Malawi, Ghana and Cameroon', *International Journal of Agricultural Sustainability* 9(1), 282–289.
Buruchara, R., Otsyula, R., Namayanja, A., Musoni, A., Mahuku, G., Opio, F., Nekesa, P., 2010, 'Partnership in managing bean root rots in Eastern and Central Africa (Rwanda, Kenya and Uganda)', in: J. Pretty, R. Hine (eds), *Sustainability, Resilience and Increased Productivity in African Food and Agricultural Systems: Summaries of Cases*, UK Foresight Global Food and Farming Futures Project, London.
Collier, P., Dercon, S., 2009, *African Agriculture in 50 Years: Smallholders in a Rapidly Changing World?* Expert Meeting on How to Feed the World in 2050, Food and Agriculture Organization, Rome, Italy.
Conway, G. R., Waage, J., 2010, *Science and Innovation for Development*, UKCDS, London.
Degenhardt, J., Hiltpold, I., Kollner, T. G., Frey, M., Gier, A., Gershenzon, J., Hibbard, B. E., Ellersieck, M. R., Turlings, T. C. J., 2009, 'Restoring a maize root signal that attracts insect-killing nematodes to control a major pest', *PNAS* 103, 13213–13218.
DFID, 2009, *Building Our Common Future in Sub-Saharan Africa*, Department for International Development, London.
Dobbs, T., Pretty, J. N., 2004, 'Agri-environmental stewardship schemes and multifunctionality', *Review of Agricultural Economics* 26(2), 220–237.
Dorward, A., Chirwa, E., 2011, 'The Malawi Agricultural Input Subsidy Programme: 2005–06 to 2008–09', *International Journal of Agricultural Sustainability* 9(1), 232–247.
Eicher, C. K., 2009, 'Building African scientific capacity in food and agriculture', *Review of Business and Economics* LIV(3), 238–257.
Fan, S., Johnson, M., Saurkar, A., Makombo, T., 2008, *Investing in Africa to Halve Poverty by 2015*, IFPRI Discussion Paper 751, IFPRI, Washington.
FAO, 2000, *The State of Food Insecurity*, FAO, Rome.
FAO, 2009a, *Enhancing Crop-Livestock Systems in Conservation Agriculture for Sustainable Production Intensification: A Farmer Discovery Process Going to Scale in Burkina Faso*, Integrated Crop Management 7, Food and Agriculture Organization, Rome.

FAO, 2009b, *World Summit on Food Security*, FAO, Rome [available at www.lisd.ca/ymb/food/wsfs2009/html/ymbvol150num7e.html].
Garforth, C., 2010, *Education, Training and Extension for Food Producers*, SR 16B, Foresight Global Food and Farming Project, London.
Giller, K., 2008, 'The successful intensification of smallholder farming in Zimbabwe', *LEISA Magazine* 24(2), 30–31.
Giller, K. E., Murwira, M. S., Dhliwayo, D. K. C., Mafongoya, P. L., Mpepereki, S., 2011, 'Soyabeans and sustainable agriculture in Southern Africa', *International Journal of Agricultural Sustainability* 9(1), 50–58.
Godfray, C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., Toulmin, C., 2010, 'Food security: the challenge of feeding 9 billion people', *Science* 327, 812–818.
Guyver, P., MacCarthy, M., 2011, 'The Ghana grains partnership', *International Journal of Agricultural Sustainability* 9(1), 35–41.
Haggblade, S., Hazell, P. (eds), 2009, *Successes in African Agriculture: Lessons for the Future*, Johns Hopkins University Press, Baltimore.
Hall, J., Pretty, J., 2008, 'Then and now: Norfolk farmers' changing relationships and linkages with government agencies during transformations in land management', *Journal of Farm Management* 13(6), 393–418.
Hassanali, A., Herren, H., Khan, Z. R., Pickett, J. A., Woodcock, C. M., 2008, 'Integrated pest management: the push–pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry', *Philosophical Transactions of the Royal Society of London, Series B* 363, 611–621.
Hassane, A., 2010, *Experience du Projet de conservation des eaux et des sols (C.E.S.) dans l'arrondissement de Illela*, Departement de Tahoua, Niger, UK Foresight Food and Farming Project, London.
IAASTD, 2009, *Agriculture at a Crossroads*, International Assessment of Agricultural Knowledge, Science and Technology for Development, Island Press, Washington, DC.
Inter Academy Council, 2004, *Realising the Promise and Potential of African Agriculture*, Inter Academy Council, Amsterdam.
IFPRI, 2004, *Ending Hunger in Africa: Prospects for the Small Farmer*, Policy Brief, International Food Policy Research Institute, Washington, DC.
Jennings, P., 2007, *Luck Is the Residue of Design*, The IRRI Pioneer Interviews, IRRI, Philippines.
Jones, R. B., Silim, S. N., 2010, *Pigeonpeas for Prosperity: East and Southern Africa*, UK Foresight Food and Farming Project, London.
Jones, M. P., Dingkuhn, M., Aluko, G. K., Semon, M., 1997, 'Interspecific *Oryza sativa* L. * *O. glaberrima* Steud. progenies in upland rice improvement', *Euphytica* 92, 237–246.
Kassam, A., Friedrich, T., Shaxson, F., Pretty, J., 2009, 'The spread of conservation agriculture: justification, spread and uptake', *International Journal of Agricultural Sustainability* 7(4), 292–320.
Khan, Z., Midega, C., Pittchar, J., Pickett, J., Bruce, T., 2011, 'Push–pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa', *International Journal of Agricultural Sustainability* 9(1), 162–170.
Kiara, J. K., 2011, 'Focal point approach: a participatory community planning approach to agricultural extension and market development in Kenya', *International Journal of Agricultural Sustainability* 9(1), 248–257.
Kilham, K., 2010, 'Integrated soil management: moving towards globally sustainable agriculture', *Journal of Agricultural Science* (in press).
Lele, U., Pretty, J., Terry, E., Trigo, E., 2010, *Transforming Agricultural Research for Development. Global Author Team, the Global Forum for Agricultural Research (GFAR)*, Report for the Global Conference on Agricultural Research (GCARD) March 2010, Montpellier, France.
Liebenehm, S., Affognon, H., Waibel, H., 2011, 'Collective livestock research for sustainable disease management in Mali and Burkina Faso', *International Journal of Agricultural Sustainability* 9(1), 212–221.
Low, J. W., Arimond, M., Oman, N., Cunguara, B., Zano, F., Tschirley, D., 2007, 'Food based approach to introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique', *Journal of Nutrition* 137, 1320–1327.
Lucas, J. A., 2010, 'Advance in plant disease and pest management', *Journal of Agricultural Science* (in press).
Marongwe, L. S., Kwazira, K., Jenrich, M., Kassam, A., Friedrich, T., 2011, 'An African success: the case of conservation agriculture in Zimbabwe', *International Journal of Agricultural Sustainability* 9(1), 153–161.
Millennium Ecosystem Assessment (MEA), 2005, *Ecosystems and Well-being*, Island Press, Washington, DC.
Miller, J. W., Atanda, T., 2011, 'The rise of peri-urban aquaculture in Nigeria', *International Journal of Agricultural Sustainability* 9(1), 274–281.
Mitei, Z., 2011, 'Growing sustainable tea on Kenyan smallholder farms', *International Journal of Agricultural Sustainability* 9(1), 59–66.
Muhanji, G., Roothaert, R., Webo, C., Stanley, M., 2011, 'African indigenous vegetable enterprises and market access for small-scale farmers in East Africa', *International Journal of Agricultural Sustainability* 9(1), 194–202.
Mwanga, R. O. M., Ssemakula, G., 2011, 'Orange-fleshed sweet potatoes for food, health and wealth In Uganda', *International Journal of Agricultural Sustainability* 9(1), 42–49.
Nestel, P., Bouis, H. E., Meenakshi, J. V., Pfeiffer, W., 2006, 'Biofortification of staple food crops', *Journal of Nutrition* 136, 1064–1067.
Norse, D., Ji, L., Leshan, J., Zheng, Z. 2001, *Environmental Costs of Rice Production in China*, Aileen Press, Bethesda, MD.
Owenya, M. Z., Mariki, W. L., Kienzle, J., Friedrich, T., Kassam, A., 2011, 'Conservation agriculture (CA) in Tanzania: the case of Mwangaza B CA farmer field school (FFS), Rhotia Village, Karatu District, Arusha', *International Journal of Agricultural Sustainability* 9(1), 145–152.
Oxfam. 2009, *Small Farmers, Big Change! Learning from Scaling Our Approach to Smallholder Agriculture*, Oxfam, Oxford.
Payne, W., Tapsoba, H., Baoua, I. B., Malick, B. N., N'Diaye, M., Dabire-Binso, C., 2011, 'On-farm biological control of the pearl millet head miner: realization of 35 years of unsteady progress in Mali, Burkina Faso and Niger', *International Journal of Agricultural Sustainability* 9(1), 186–193.
Pingali, P. L., Roger, P. A., 1995, *Impact of Pesticides on Farmers' Health and the Rice Environment*, Kluwer, Dordrecht.
Pretty, J., 2003, 'Social capital and the collective management of resources', *Science* 302, 1912–1915.
Pretty, J., 2008, 'Agricultural sustainability: concepts, principles and evidence', *Philosophical Transactions of the Royal Society of London, Series B* 363(1491), 447–466.
Pretty, J., Shah, P., 1997, 'Making soil and water conservation sustainable: from coercion and control to partnerships and participation', *Land Degradation and Development* 8, 39–58.

Pretty, J., Lang, T., Ball, A., Morison, J., 2005, 'Farm costs and food miles: an assessment of the full cost of the weekly food basket', *Food Policy* 30(1), 1–20.
Reij, C. P., Smaling, E. M. A., 2008, 'Analyzing successes in agriculture and land management in Sub-Saharan Africa: is macro-level gloom obscuring positive micro-level change?', *Land Use Policy* 25, 410–420.
Röling, N., 2010, *Africa Can Feed the World*, SR 16A, Foresight Global Food and Farming Project, London.
Roothaert, R. L., Ssalongo, S., Fulgensio, J., 2011, 'The Rakai Chicken Model: an approach that has turned around fortunes for Ugandan farmers', *International Journal of Agricultural Sustainability* 9(1), 222–231.
Royal Society, 2009, *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture*, Royal Society, London.
Sawadogo, H., 2011, 'Rehabilitation of degraded lands by using soil and water conservation techniques in the northwestern region of Burkina Faso', *International Journal of Agricultural Sustainability* 9(1), 120–128.
Settle, W., Hama Garba, M., 2011, 'The FAO integrated production and pest management programme in the Senegal and Niger river basins of francophone West Africa', *International Journal of Agricultural Sustainability* 9(1), 171–185.
Sherwood, S., Cole, D., Crissman, C., Paredes, M., 2005, 'Transforming potato systems in the Andes', in: J. Pretty (ed), *The Pesticide Detox*, Earthscan, London.
Silici, L., Ndabe, P., Friedrich, T., Kassam, A., 2011, 'Harnessing sustainability, resilience and productivity through conservation agriculture: the sase of *Likoti* in Lesotho', *International Journal of Agricultural Sustainability* 9(1), 137–144.
Smith, P., 2008, 'Soil organic carbon dynamics and land use', in: A. K. Braimoh, P. L. G. Vlek (eds), *Land Use and Soil Resources*, Springer, Netherlands.
Spielman, D. J., Pandya-Lorch, R., 2009, *Millions Fed*, IFPRI, Washington, DC.
Styger, E., Aboubacrine, O., Ag Attaher, M., Uphoff, N., 2011, 'The system of rice intensification (SRI) as a sustainable agricultural innovation: introducing, adapting and scaling-up SRI practices in the Timbuktu region of Mali', *International Journal of Agricultural Sustainability* 9(1), 67–75.
Tegtmeier, E. M., Duffy, M. D., 2004, 'External costs of agricultural production in the United States', *International Journal of Agricultural Sustainability* 2(1), 1–20.
Tittonell, P., van Wijk, M. T., Herrero, M., Rufino, M. C., de Ridder, N., Giller, K. E., 2009, 'Beyond resource constraints: exploring the biophysical feasibility of options for the intensification of smallholder crop-livestock systems in Vihiga district, Kenya', *Agricultural Systems* 101, 1–19.
Tomekpe, K., Ganry, J., 2011, 'CARBAP and innovation on the plantain banana in West and Central Africa', *International Journal of Agricultural Sustainability* 9(1), 264–273.
Toulmin, C., 2009, *Climate Change in Africa*, Zed Press, London.
Traore, A., Bickersteth, S., 2011, 'Taking on the challenges of agricultural service provision: the case of Oxfam's strategic cotton programme in Mali', *International Journal of Agricultural Sustainability* 9(1), 82–90.
Tripp, R., 2005, *Self-Sufficient Agriculture: Labour and Knowledge in Small-scale Farming*, Earthscan, London.
UNEP, 2008, *Africa: Atlas of Our Changing Environment*, UNEP, Nairobi, Kenya.
Van Mele, P., 2010, *Zooming-in Zooming-out: Videos to Scale up Sustainable Technologies and Build Livelihood Assets*, UK Foresight Food and Farming Project, London.
Wambugu, C., Place, F., Franzel, S., 2011, 'Research, development and scaling-up the adoption of fodder shrub innovations in East Africa', *International Journal of Agricultural Sustainability* 9(1), 100–109.
Wiggins, S., 2009, 'Can the smallholder model deliver poverty reduction and food security for a rapidly growing population in Africa?' Expert Meeting on How to Feed the World in 2050, Food and Agriculture Organization, Rome.
Wiggins, S., Slater, R., 2010, *Food Security and Nutrition: Current and Likely Future Issues*, SR27, Foresight Global Food and Farming Project, London.
Williamson, S., Ball, A. S., Pretty, J., 2008, 'Trends for pesticide use and safer pest management in four African countries', *Crop Protection* 27, 1327–1334.
Woolcock, M., 1998, 'Social capital and economic development: towards a theoretical synthesis and policy framework', *Theory and Society* 27, 151–208.
Woolcock, M., 2001, 'The place of social capital in understanding social and economic outcomes', ISUMA, *Canadian Journal of Policy Research* 2, 11–17.
World Bank, 2008, *Agriculture for Development: World Development Report 2008*, Washington, DC.
Wright, J., 2010, *Feeding Nine Billion in a Low Emissions Economy*, ODI, London.
Zhao, F.-J., Shewry, P. R., 'Recent developments in modifying crops and agronomic practice to improve human health', *Food Policy* (in press).