Multifunctional Agriculture in the Tropics: Overcoming Hunger, Poverty and Environmental Degradation

Pedro A. Sanchez

Abstract

Agricultural sustainability at the dawn of the 21st century is now seen in a multifunctional context: food security, poverty reduction and environmental enhancement. Participatory approaches are now mainstream and no longer the exception. The comparative advantages of smallholder farming lie in intensification and diversification of high-value products. Biophysical research now goes in tandem with policy research. Poverty includes in addition to income, extreme vulnerability to risk, and lack of voice in decision-making. More intensive global warming is now expected and will adversely affect the poor in the tropics. Improvements in the productive, human well-being and environmental dimensions seldom provide win-win-win situations, so tradeoffs have to be addressed by negotiation between the various stakeholders. The case of soil fertility replenishment in Africa is given as an example of the multifunctional nature of agricultural development. A robust natural resources management approach was developed, bringing nitrogen from the air fixed by leguminous tree fallows, phosphorus from indigenous phosphate rock deposits, and additional nutrients and carbon rapidly released from biomass transfers of the nutrient-accumulating shrub *Tithonia diversifolia*. Tens of thousands of farm families are becoming food-secure because of the large maize grain yield increases attained. Some farmers are taking their first steps out of poverty by shifting to vegetable crops, dairy and high-value trees. Many community-based organizations are disseminating the technologies, feeling empowered to make decisions such as establishing credit schemes. Soil fertility replenishment techniques can triple carbon stocks, representing one of the highest options for carbon sequestration by agriculture. The tradeoffs between private farmer benefits and global environmental benefits need to be negotiated under mechanisms like the Kyoto Protocol, so that farmers can receive financial benefits for the carbon they remove from the atmosphere. The main challenge is to scale-up these robust technologies from tens of thousands to tens of millions of African farmers.

Introduction

The agricultural performance of the world tropical regions has been outstanding in the last half of the 20th century. Against Malthusian predictions of worldwide starvation during the 1950s and 60s, farmers in tropical countries have tripled cereal production, keeping food production ahead of population growth, while the real prices of rice, wheat and maize decreased by 76% in the last four decades (Table 1). The Green Revolution is one of the main achievements of humankind during the past century, and was due to a successful combination of scientific research, political will and effective farmers in developing countries.

Director General, International Centre for Research in Agroforestry, Nairobi, Kenya
p.sanchez@cgiar.org

As we enter the 21st century, the challenges to tropical agriculture are shifting from production agronomy to a more multifunctional character. There is a widely shared belief that countries in the tropics in the next 25 years must double food production, reduce the number of hungry people by half, get 1.2 billion rural poor out of absolute poverty, get millions off the farm, as well as stabilize greenhouse gases, biodiversity and watershed functions (Pinstrup-Andersen *et al.*, 1999; Sanchez, 2000). The tropical countries must do it all at the same time, optimizing tradeoffs.

Agricultural sustainability is the ability of farmers to produce sufficient food and fiber over time, without depleting the natural capital on which future generations depend. Fagi (2001) outlined five basic principles of sustainability to which I have added one:

* Human births cannot exceed human deaths
* Soil erosion cannot exceed soil formation
* Losses of soil nutrients cannot exceed additions of nutrients to the soil
* Forest destruction cannot exceed forest regeneration
* Carbon emissions cannot exceed carbon fixation
* Species extinction cannot exceed species evolution

The tropics have a long way to go in meeting these principles. Human population growth will continue to outstrip deaths until the world population stabilizes at about 9 billion people by 2050. More than 90% of this growth will take place in the tropics. The rates of soil erosion and nutrient depletion continue to outstrip rates of soil formation and nutrient inputs, particularly in Africa. In many temperate regions, the nutrient principle has been perverted when nutrient inputs exceed nutrient outputs, creating nutrient pollution, the efflux of affluence. Forest destruction continues to exceed forest regeneration by a wide margin in the tropics, with about one hectare of tropical forests being slashed and burned every 2 1/2 minutes, emitting in the process large quantities of greenhouse gases and ravaging plant and animal biodiversity (Pinstrup-Andersen *et al.*,1999; Sanchez, 2000). International agricultural research can play a critical role in the adaptation to and mitigation of climate change.

Table 1 The Green Revolution more than has tripled cereal grain production and dropped their prices by 79% in the past 38 years (Source: Prabhu Pingali CIMMYT).

Cereal Grain	Production (million metric tons/year)			Prices (1990 US$ per metric ton)		
	1961	1999	% increase	1961	1999	% decrease
Wheat	60	280	467	265	70	74
Maize	70	280	400	205	70	65
Rice	200	580	290	580	80	86
Mean			345			79

The changing paradigms

Agricultural productivity is now seen in a wider context, consisting of three main elements: food security, poverty reduction and the environment (TAC, 2000). The nature of agricultural research is also evolving to embrace this wider context by combining three main functions: production, human well-being and the provision of environmental benefits (CGIAR, 2000).

Production The production paradigm has changed from increasing crop yields to providing food security for all. Food security encompasses the capacity to produce sufficient and nutritious food or the capacity of farmers to purchase it. Food insecurity in rampant in South Asia and sub-Saharan Africa where over 800 million people are hungry and malnourished (Pinstrup-Andersen *et al.*,1999). Farmers may attain food security by producing all the food they need or by selling high-value products like tree resins and fruits produced in complex agroforests of Indonesia and buying rice from their neighbors (Bouamrane, 1996). Economies of scale favor the production of basic food crops in large mechanized farms, while smallholder farms in the tropics are intrinsically better suited to grow crops, livestock, fish and tree species that provide high-value products, maximizing the productivity of labor (Sanchez *et al.*, 1997; Kherallah *et al.*, 2000). Farm size is not going to increase in the tropics, so intensification and diversification are more sensible options than just growing basic food crops on a small scale.

To support these changes, agricultural research is shifting from single discipline, station-bound research to team-based participatory, interdisciplinary approaches that combine cutting-edge laboratory research with on-farm and policy research. Such research has multiple stakeholders on the farm, community, watershed, regional, national and global scales (CGIAR, 2000). The straightforward technological fixes of the Green Revolution are largely over. Recent advances in systems research now provide successful models of how such work can be done in tandem (Izac and Sanchez, 2000). Complex issues such as genomics, natural resources management, the digital divide, the focus on marginal lands, intellectual property, and private vs. global public goods add multifaceted dimensions to what was simply tropical agriculture. The purpose of agricultural research now is to provide a range of flexible, adaptive options to farmers and policy-makers, rather than "silver bullets" or technology packages as in the past. In hindsight, this approach would have also benefited agricultural research during the Green Revolution days, but complexity was not acknowledged then because the research approach was overwhelmingly reductionist.

The division between the two main biophysical research "pillars", genetic improvement and natural resources management is beginning to be breached by the search for synergies between them (CGIAR, 2000). Also, biophysical research now goes in tandem with policy research and policy dialogue, as two sides of the same coin, because the food security-poverty-environment problems now tackled are complex enough to require both technological and policy innovations (Sanchez, 1995). Participatory approaches are now mainstream and no longer the exception. Research now attempts to combine the best of frontier science with the best of indigenous knowledge (TAC, 2000).

Poverty About one-fifth of the world population (1.2 billion people) lives in absolute poverty, measured as incomes of less than US $ 1 per person per day. Most of the poor live in the tropics, roughly 70% in rural areas and the rest in urban slums. Seventy percent of the absolute poor are women. Poverty now is a multidimensional concept including in addition to income, extreme vulnerability to risk, and lack of voice and political rights (Narayan, 2000). Indicators of decreasing poverty include increases in income, the stability of that income increase, risk-buffering capacity, increased participation in decisions and a sense of empowerment.

Environment The global environment continues to deteriorate. More scientifically robust predictions now indicate a higher level of global warming than previously estimated. There is clear evidence that the Earth surface has warmed by an average of 0.6 ℃ during the 20th century, and more robust predictions are that it will warm by an additional 1.5 to 6.0 ℃ during the 21st century (IPCC, 2001). The consequences are largely negative and will adversely affect the poor in the tropics the most. More frequent and severe extreme weather events already accompany the above changes, because the hydrological cycle has more energy. The incidence of pests and disease is likely to increase (Rosenzweig and Hillel, 1998). Less rainfall is predicted for southern Africa, Southeast Asia, parts of India and the Caribbean, while more rainfall is predicted for parts of East Africa, Sri Lanka, Ecuador, Peru, Northeast Brazil and the southern cone of South America. Biodiversity losses continue unabated, particularly in coral reefs and rainforests. Fresh water supplies continue to deteriorate; 70% of the world population will be at stress levels of available fresh water by 2050. Most of the tropics, therefore face a severe depletion of natural resources in the coming decades (Sanchez, 2000).

International agricultural research can play a critical role in adaptation to and mitigation of climate change. The CGIAR Intercentre Working Group on Climate Change has developed a research strategy that incorporates adaptation to and mitigation of climate change into the international agricultural research agenda (Sanchez *et al.*, 2000a). Research on genetic improvement must develop new strains of crops, livestock, fish and trees that are adapted to the expected changes of climate in key regions. Since farmers manage the largest share of the world terrestrial resources, land use intensification and changing from one type of land use to an environmentally better one, can make a major contribution to mitigating climate change. A recent study conducted by the Intergovernmental Panel on Climate Change shows the enormous potential for sequestering carbon with various land use improvements, as well as land use change from degraded croplands and grasslands to agroforestry in the tropics (Watson *et al.*, 2000). Table 2 shows how tropical farmers can make a major and decisive contribution to decreasing global warming in the next decades.

Table 2 Carbon sequestration potential of agricultural activities in developing (non-Annex 1) countries according to the special report on Land Use, Land Use Change and Forestry of the Intergovernmental Panel on Climate Change (Watson *et al.*, 2000)

Agricultural activity	C sequestration rate (ton C/ha/year)	Annual potential by 2040 (million ton C/year)
Land use intensification:		
Croplands (reduced tillage, rotations, cover crops, fertilization and irrigation)	0.36	126
Forest lands (forest regeneration, better species, silviculture)	0.31	200
Grasslands (betterherds, woody plant and fire management)	0.80	337
Land use change:		
Agroforestry (conversion from unproductive croplands and grasslands)	3.10	586

Tradeoffs

Improvements in the productive, human well-being and environmental dimensions seldom provide win-win-win situations, so tradeoffs must be addressed by the relevant stakeholders, usually by negotiation. Figure 1, product of the search for alternatives to slash and burn agriculture in the Congo Basin, aligns various management options in terms of a global benefit (carbon sequestration) vs. a private benefit (farmer profitability). There are no real win-win situations in this case (high carbon, high profit), but there is a lose-lose one (low carbon, low profit). Optimal tradeoffs can take place in choosing among a range of options that provide moderate levels of carbon sequestration with high levels of farmer profitability (Fig. 1).

The concept of " win-win" however, requires some elaboration. In the sense that everybody should get what he/she fully desires (such as high carbon, high profit), complete win-win situations are indeed rare. But if one thinks of a partial win-win as a situation in which each of the respective parties gets more of what he/she wants than they would have gotten if the conflict continues to persist without resolution, then there are actually many possible win-win scenarios. An example is agreements on land rights to local communities in return for their involvement in the protection of watershed services, as ICRAF has seen in Krui, Indonesia, Mae Chaem, Thailand and Mindanao, Philippines (Garrity *et al.*, 2001). Thus, there are important opportunities for realistic win-wins to be achieved, as long as their defining characteristic is that everybody gets more of what he/she wants, rather than everything they want.

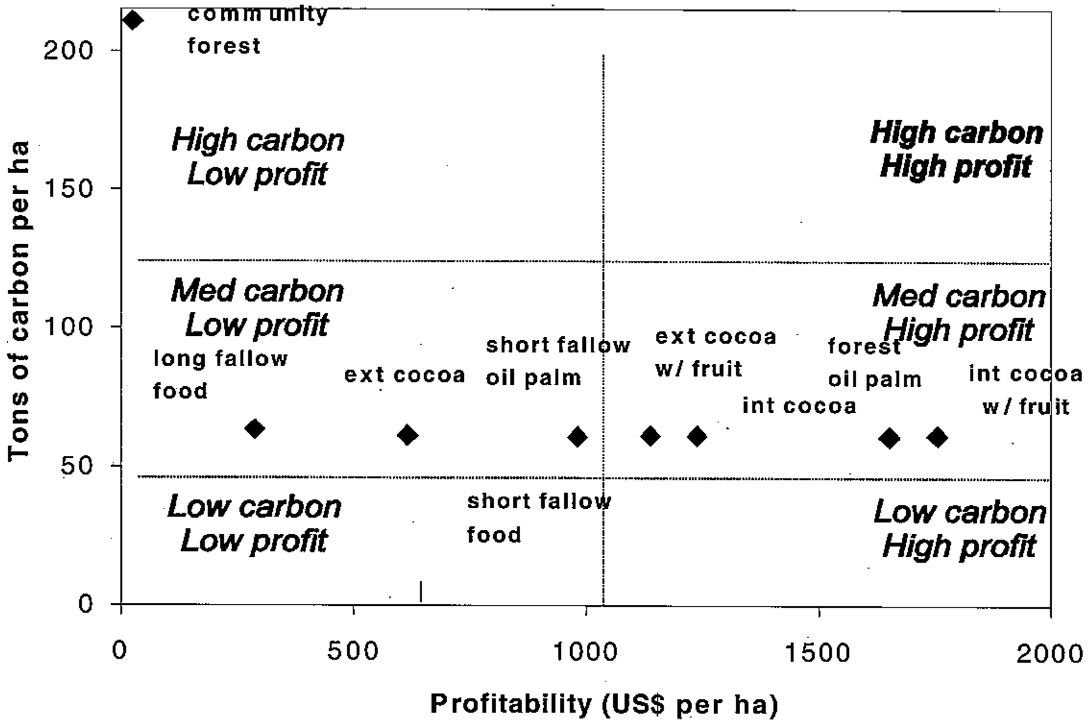

Fig. 1 **Carbon sequestration and profitability trade-offs in different alternative systems to slash and burn agriculture in southern Cameroon. Carbon figures are time-averaged system carbon stocks**
Source: Gokowski *et al.*, 2000.

Working across the research-development continuum

Gone are the days when developing a new technology, publishing it in scientific journals, producing the initial germplasm, training national partners and convincing a few policy-makers was sufficient to trigger large-scale impact. Such approaches worked well where straightforward genetic improvements in food crops were the principal innovations, food production was the only goal and relatively homogeneous farmlands were the targets of research and development. However, this approach is clearly insufficient to address the multifunctional paradigm. ICRAF has assumed a more hands-on, proactive role in identifying, understanding, facilitating and catalyzing agroforestry-based opportunities for greater adoption and impact by creating a Development Division to work with partners in applied and adaptive research, pilot development projects and full development efforts.

Such an integration of research and development responsibilities (Fig. 2) departs from traditional institutional approaches that separate research and extension. Participatory approaches further blur the traditional research-extension divide. By engaging directly in the development process through strategic partnerships, impact on food security, poverty reduction and environmental protection will be realized more quickly and on a larger scale than if research institutions continue the more passive approach of the past. Early 21st century research institutions will not become development institutions as they have no comparative advantage—- but would become credible science-based partners across the entire research-development continuum. In addition, there is a legitimate global public good research need: to understand the adoption process of flexible, adaptive options, which is likely to be different from the process of adopting a new crop variety (ICRAF, 2000).

A general framework for conducting integrated natural resources management research is shown in Fig. 3, summarizing how the multifunctional paradigm can be implemented by research institutions (CGIAR, 2000). A specific example illustrates this approach.

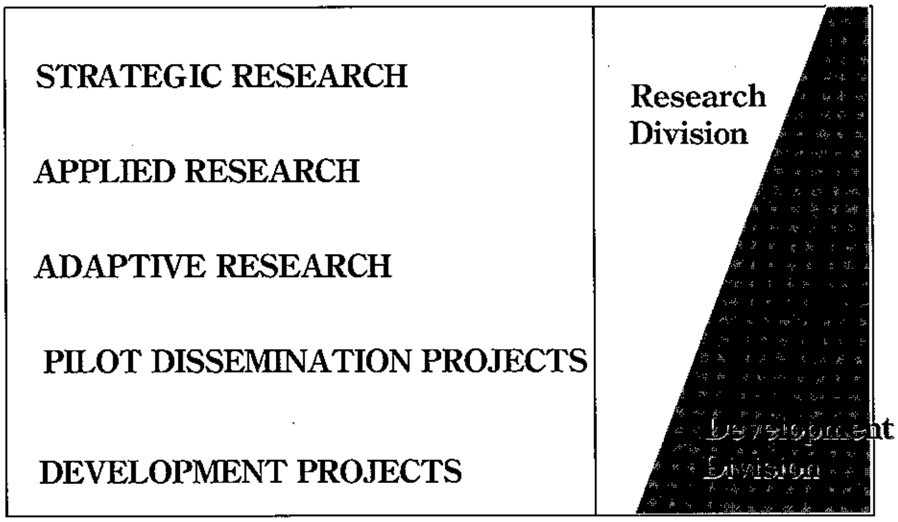

Fig. 2 The research-development continuum in international agricultural research and the varying role of ICRAF's research and development divisions. Source: ICRAF, 2000.

An example of the multifunctional paradigm: soil replenishment in Africa

Major positive changes have taken place over the last five years in soil fertility replenishment, a key entry point for achieving food security, reducing poverty and preserving the environment in smallholder farms of sub-Saharan Africa (Sanchez *et al.*, 1997, 2001; Buresh *et al.*, 1997; Sanchez and Jama, 2001). The need for soil fertility replenishment in Africa now is analogous to the need for Green Revolution-type germplasm in Asia four decades ago—-they are both the fundamental root causes and therefore the key entry point to tackle food insecurity.

During the 1960s, the fundamental root cause for declining per capita food production in Asia was the lack of high-yielding varieties of rice and wheat. Food security was only effectively addressed with the advent of improved germplasm. Then other key aspects that had been largely ineffective (enabling government policies, irrigation, seed production, fertilizer use, credit, pest management, research and extension services) came in support of the new varieties. Soil fertility depletion is the fundamental root cause of food insecurity in much of rural Africa now, and therefore the logical entry point. After soil fertility is replenished, other key aspects, including improved germplasm can be effectively tackled to attain food security plus others to eliminate poverty.

Problem identification The first step as outlined in Fig. 3 is to identify the problem by participatory diagnosis exercises with farmers and policy-makers (Hoekstra, 1988; Ngugi *et al.*, 1988). Farmers have consistently identified declining soil fertility as one of their main limiting factors in such exercises. Nitrogen depletion is uniform while phosphorus depletion is particularly severe in the Lake Victoria Basin. Smallholder farms in East and southern Africa range from 0.5 to 5 hectares. The vast majority of farmers have cash incomes of less than US$1 per day, farm families are large and endure 3 - 5 hunger months when they eat little. The children are malnourished and a quarter of the people are HIV-positive. Women do most of the farming, fuelwood gathering and water fetching—very hard work. Men do much of the off-farm work. Maize,

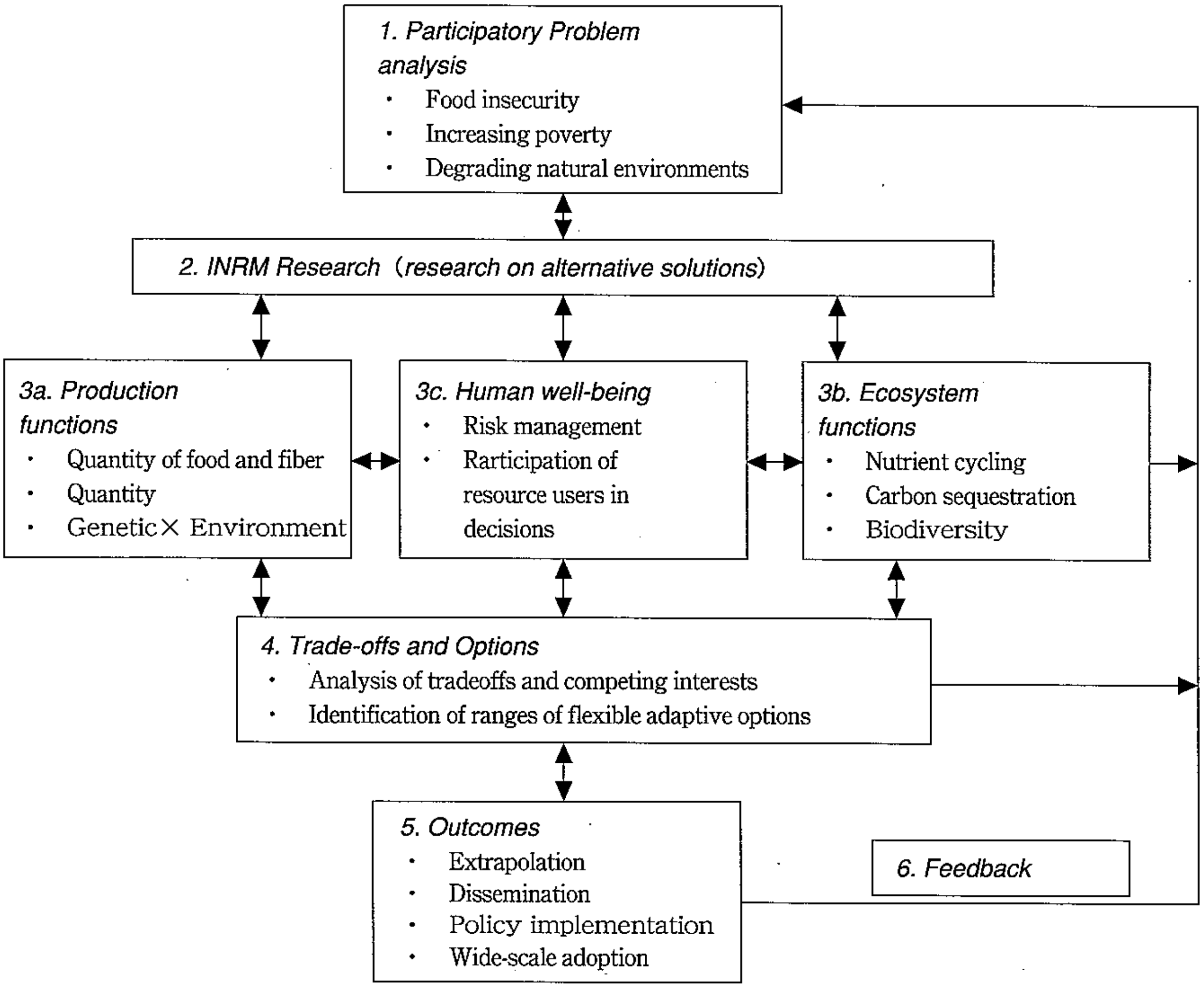

Fig. 3 Framework model of the new research process (CGIAR, 2000)

the staple food, yields about 1 ton ha-1 of grain. In spite of the small farm size, many fields are left to weedy fallows often because of their low yield potential (Kwesiga *et al.*, 1999).

Since fertilizers cost about 2 - 4 times more at the farm gate in Africa than in Japan, Europe or North America, the traditional approach needed an alternative one. A robust natural resources management approach was developed jointly by a team of scientists from national research systems, ICRAF and TSBF (Tropical Soil Biology and Fertility Programme), working with farmers and NGOs in eastern Zambia and western Kenya.

Research approach The approach consists of bringing nitrogen from the air and phosphorus from indigenous phosphate rock deposits, together with biomass transfers of a nutrient-accumulating hedge species as a source of rapidly available nutrients and carbon. Numerous researcher-designed and managed trials (on-farm and on-station), followed by hundreds of farmer-designed and managed trials were conducted in Zambia, Kenya, Malawi, Zimbabwe and Uganda. The results are described in several publications (Kwesiga and Coe, 1994; Niang *et al.*, 1996, 1998; Rao *et al.*, 1998; Jama *et al.*, 1998, 2000; Kwesiga *et al.*,1999; Mafongoya and Dzowela, 1999; Franzel, 1999; Rutunga *et al.*, 1999; Wamuongo and Jama, 2000), and provided positive and consistent results. Leguminous tree fallows of several species of *Sesbania, Tephrosia, Crotalaria* and *Cajanus* accumulate 100 - 200 kg N ha-1 in 6 months to 2 years in their above- and below-ground biomass. After removal of fuelwood, the remaining biomass nitrogen is incorporated into the soil before planting, increasing maize yields 2 - 4 times. An example is shown in Table 3. These fallows also provide multiple benefits such as *in situ* fuelwood production, capture of leached nitrates, recycling of other nutrients (particularly potassium), striga control, improved soil physical properties, waters-holding capacity and carbon

Table 3 Nitrogen yield of biomass (leaves plus twigs < 2 cm diameter) of 6-month-old improved fallow species in western Kenya in a researcher-managed on-farm trial (Fallows were established from 2-month old seedlings (Source: James Kamiri Ndufa, KEFRI, unpublished)

Species	Nitrogen yield (kg N ha^{-1})
Crotalaria grahamiana	152.6
Tephrosia vogelii	121.3
Sesbania sesban	85.4
SED	11.5

Table 4 Combining *Tithonia diversifolia* biomass transfer (1.8 ton ha^{-1} of dry mass) with Minjingu phosphate rock (PR) and triple superphosphate (TSP) both applied at a recapitalization rate of 250 kg P ha^{-1}, on maize grain yield Mean of 3 researcher-managed on-farm trials on Oxisols near Maseno, Kenya. The amounts of N supplied by urea and *T. diversifolia* were the same, 60 kg N ha^{-1}. Source: Sanchez and Jama, 2001.

Source	Phosphorus rate (kg P ha^{-1})	N source: Urea	N source: Tithonia
		Maize grain yield (tons ha^{-1})	
None	0	0.9	2.1
TSP	50 every year	4.1	4.4
Minjingu PR	50 every year	3.9	4.0
TSP	250 once in 5 years	4.5	4.8
Minjingu PR	250 once in 5 years	4.4	4.3
SED		0.3	0.2

sequestration (Sanchez and Jama, 2001).

Experiments in western Kenya, an area of widespread phosphorus deficiency and high P-fixation, have provided a series of flexible options for replenishing phosphorus, one large "recapitalization" rate vs. small annual additions, and indigenous phosphate rocks vs. imported superphosphates, as well as biomass transfers of hedge shrubs. A single recapitalization application of Minjingu phosphate rock (125 - 250 kg P ha-1), or small annual additions were found to double or triple maize yields in P-deficient soils nearly as efficiently as imported triple superphosphate (Table 4). Minjingu phosphate rock does so at a lower cost and the residual effects last for at least five years (Jama, 1999). Tithonia (*Tithonia diversifolia*) a common hedge shrub has been found to have high nutrient concentrations in its leaves and soft stems (3.5% N, 0.37% P and 4.1 % K) which decompose rapidly upon incorporation into the soil (Gachengo *et al.*, 1999; Jama *et al.*, 2000). Biomass transfers of tithonia at dry mass rates of 2 - 5 ton ha-1 routinely double maize yields without fertilizer addition and are twice as effective as urea when applied at the same nitrogen rate, possibly because of the addition of other nutrients and carbon (Jama *et al.*, 2000).

Tree fallows therefore can provide the basal nitrogen application, which can be supplemented by topdressing applications with mineral nitrogen fertilizers or tithonia biomass as needed. Where phosphorus is limiting, several replenishment strategies are available, using phosphate rock, superphosphates or tithonia biomass transfers as phosphorus sources that can be applied at different times and rates. Research, therefore, is providing a basket of flexible options that farmers can incorporate as components into their ongoing systems in a wide variety of ways.

Production Tens of thousands of farm families are becoming food-secure and no longer suffer from hunger periods because of the large maize grain yield increases attained by these technologies (Kwesiga *et al.*, 1999; Wamuongo and Jama, 2000; Sanchez and Jama, 2001), which satisfies the production dimension, albeit on a relatively small scale.

Sesbania fallows are financially attractive both in East and southern Africa (Jama *et al.*; 1998; Kwesiga *et al.*; 1999; Place *et al.*, 2000). The returns to labor from a 2-year fallow, 3-year maize rotation were US$ 3.45 per day, which is 70% more than from continuous monocropped maize without fertilization in Zambia (Franzel and Place, 2000).

Human well-being Hundreds of farmers are now taking advantage of their improved soils by diversifying and growing valuable vegetable crops and trees, and many are beginning to have a dairy cow for the first time, taking the first steps out of poverty. One farmer has increased his annual cash income from US$91 to 1,665 after shifting from maize to kale (*Brassica oleracea* cv. *acephala*) fertilized with tithonia biomass transfers (Nyasimi *et al.*, 1997). This income now goes primarily to send children to school. Larger profits can be expected when farmers move to high-value tree products such as the bark from *Prunus africana*. This is a timber tree indigenous to montane regions of Africa from which a substance is extracted from the bark to treat prostate gland-related diseases, with an annual market value of US $220 million (Simons *et al.*, 1998).

Many community-based organizations including women groups are disseminating the technologies from village to village. They feel empowered to make some decisions, including establishing credit schemes (Wamuongo and Jama, 2000; Sanchez and Jama, 2001). Extension workers also feel empowered, because for the first time in much of their professional life they have real practical advice to offer to farmers. Tree fallows as small as half a hectare provide the firewood needed for the family to cook for one year (Sanchez and Jama, 2001). This eliminates the need for women farmers to travel long distances to collect and carry fuelwood, saving time and energy. These are examples of the human well-being dimension beginning to appear.

Environmental services When soil fertility is replenished, preliminary estimates suggest that carbon is sequestered at rates averaging 1.5 ton C ha-1 year-1. These rates include both above- and below-ground carbon as is time-averaged, to account for the carbon removals in fuelwood and crop harvests. When high-value trees are planted on field boundaries and as orchards, turning the entire farm into an intensive agroforestry system, such carbon sequestration rates are estimated to reach as much as 3.5 ton C ha-1 year-1 (Sanchez, 2000). Soil fertility replenishment practices based on improved fallows, phosphate rock, and tithonia biomass transfers plus the planting of high-value trees is estimated to triple carbon stocks in a 20-year period. This represents one of the highest options for carbon sequestration by agriculture (Watson *et al.*, 2000).

The provision of fuelwood in farms by tree fallows helps prevent further encroachment of nearby woodlands, contributing to the remaining biodiversity.

Soil conservation also increases in fertility-replenished lands because of the constant plant cover throughout the year and the many contour bunds farmers make to prevent the erosion of their recapitalized soils while growing tithonia or leguminous fodder trees (Rao *et al.*, 1998; Jama, 1999). Land degradation, therefore is effectively addressed.

Tradeoffs The tradeoffs between private farmer benefits (food security, increased human well-being) and global environmental benefits (carbon sequestration, biodiversity conservation) need to be negotiated. This could be done under the Kyoto Protocol's proposed Clean Development Mechanism, so that smallholder farmers of Africa receive financial benefits or enjoy an enabling policy environment, better access to education, health and markets in return of providing benefits for all humankind (Sanchez, 2000). Enabling policies include improving the availability of fertilizers at a reasonable price, training of extension agents, providing local access to credit at reasonable interest rates and improving the road and market infrastructure (Place and Dewees, 1999).

Outcome

Tens of thousands of farmers in east and southern Africa are using these technologies with consistent results and their food security achieved, and a few of them beginning to take the first steps out of poverty. The challenge is to scale-up to tens of millions of African farmers that face similar constraints. An Africa-wide soil fertility initiative is now at different stages of implementation in many African countries (FAO, 1998; Wamuongo and Jama, 2000; Toure, 2000). The elimination of this root cause of food insecurity in Africa augurs well for turning around the poverty-environmental spiral in this continent.

References

1) Bouamrane, M. (1996): The season of gold-putting a value on harvests from Indonesian agroforests. Agrofor. Today 8 (1), 8-10.
2) Buresh, R. J., Sanchez, P. A. and Calhoun, F. (eds.) (1997): Replenishing soil fertility in Africa, SSSA Special Publication No. 51: Soil Science Society of America, Madison, Wisconsin, 251 p.
3) CGIAR (2000): Integrated natural resource management research in the CGIAR. A brief report on the INRM workshop, Penang, Malaysia, 21-25 August, 2000: CIFOR, Bogor, Indonesia, 50 p.
4) Fagi, A. M. (2001): Developing sustainable agricultural systems: determinants, future approaches and the role of different partners. 7th JIRCAS International Symposium, Tsukuba, Japan, 7 p.
5) FAO (1998): Soil fertility initiative. Food and Agriculture Organization of the United Nations, Rome.
6) Franzel, S. (1999): Socioeconomic factors affecting the adoption of potential improved tree fallows. Agrofor. Syst. 47, 305-321.
7) Franzel, S. and Place, F. (2000): Improved fallows in Eastern Zambia: background and economic analysis. ICRAF Nairobi, Kenya, 2p.

8) Gachengo, C. N., Palm, C. A., Jama, B. A. and Othieno, C. (1999): Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in western Kenya. Agrofor. Syst. 44, 21-36.

9) Garrity, D. P., Amoroso, V. B., Koffa, S., Catacutan, D., Buenavista, G., Fay, C. and Dar, W. (2001): Integrated natural resource management on the poverty-protection interface in an Asian Watershed. J. Conserv. Ecol. 13 p. (submitted).

10) Gokowski, J., Nkamelu, B. and Wendt, J. K. (2000): Implications of resource use intensification for environment and sustainable technology systems in the Central African rainforest. In Tradeoffs or Synergies?, D. R. Lee and C. B. Barrett (eds.): CABI, Wallingford, UK. (in press).

11) Hoekstra, D. (1988): Summary of the zonal agroforestry potentials and research across land use systems in the highlands of eastern and central Africa. AFRENA Report No. 5: International Centre for Research in Agroforestry, Nairobi, Kenya.

12) ICRAF (2000): Paths to prosperity through agroforestry. ICRAF's corporate strategy 2001-2010: International Centre for Research in Agroforestry, Nairobi, Kenya, 43 p.

13) IPCC (2001): Third assessment report. Intergovernmental Panel on Climate Change (in press).

14) Izac, A. -M. N. and Sanchez, P.A. (2000): Towards a natural resource management research paradigm: an example of agroforestry research. Agric. Syst. (in press).

15) Jama, B. A., Buresh, R. J. and Place, F. M.(1998): Sesbania tree fallows on phosphorus-deficient sites: maize yields and financial benefit. Agron. J. 90, 717-726.

16) Jama, B. A. (1999): Phosphate rock application for rebuilding the productive capital of African soils: Experiences from East Africa. African Fertilizer Market, 12 (12): IFDC-Africa, Lome, Togo, 23-28.

17) Jama, B. A., Palm, C. A., Buresh, R. J., Niang, A. I., Gachengo, C., Nziguheba, G. and Amadalo, B.(2000): *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: a review. Agrofor. Syst. 49, 201-221.

18) Kerallah, M., Delgado, C., Gabre-Mahdin, E., Minot, N. and Johnson, M. (2000): The road half traveled. Agricultural market reform in Sub-Saharan Africa. Food policy report: International Food Policy Research Institute, Washington, D.C., 25p.

19) Kwesiga, F. R. and Coe, R. (1994): The effect of short rotation *Sesbania sesban* planted fallows on maize yields. For. Ecol. Management 64, 199-208.

20) Kwesiga, F. R., Franzel, S., Place, F., Phiri, D. and Simwanza, C.P. (1999): Sesbania improved fallows in eastern Zambia: their inception, development and farmer enthusiasm. Agrofor. Syst. 47, 49-66.

21) Mafongoya, P. L. and Dzowela, B. H. (1999): Biomass production of tree fallows and their residual effect on maize in Zimbabwe. Agrofor. Syst. 47, 163-196.

22) Narayan, D. (2000): Voices of the poor. Can anyone hear us?: Oxford University Press, New York, 343 p.

23) Ngugi, D. N. (1988): Agroforestry research project for the maize/livestock system in the unimodal upland plateau of Eastern Province (Chipata and Katete districts), Zambia. AFRENA Report No 10: International Centre for Research in Agroforestry, Nairobi, Kenya.

24) Niang, A. I., Gathumbi, S. and Amadalo, B. (1996): The potential of short-duration improved fallows for crop productivity enhancement in the highlands of western Kenya. In People and institutional participation in agroforestry for sustainable development, Proceedings of the First Kenya Agroforestry Conference, J. O. Mugah (ed.): Kenya Forestry Research Institute, Nairobi, Kenya. pp. 218(230).

25) Niang, A. I., de Wolf, J., Nyasimi, M., Hansen, T. S., Romelsee, R. and Mdewa, K. (1998): Soil fertility replenishment and recapitalization project in western Kenya, Progress Report February 1997- July 1998. Pilot Project Report No. 9: Maseno Regional Agroforestry Research Centre, Maseno, Kenya. 42 p.

26) Nyasimi, M., Niang, A. I., Amadalo, B. and Obonyo, E. (1997): Using the wild sunflower, tithonia, in Kenya: ICRAF, KARI and KEFRI, Nairobi, Kenya, 12 p. (English and Kiswahili versions).

27) Pinstrup-Andersen, P., Pandhya-Lorch, R. and Rosengrant, M. W. (1999): World food prospects: Critical issues for the early 21st century. 2020 vision food policy report: International Food Policy Research Institute, Washington, 32 p.

28) Place, F. and Dewees, P. (1999): Policies and incentives for the adoption of improved fallows. Agrofor. Syst. 47, 323-343.

29) Place, F., Wangila, J., Rommelse, R. and De Wolf, J. (2000): Economics of agroforestry technologies in the Pilot Project area in Western Kenya. ICRAF, Nairobi, Kenya, 4 p

30) Rao, M. R., Niang, A. I., Kwesiga, F. R., Duguma, B., Franzel, S., Jama, B. A. and Buresh, R. J. (1998): Soil fertility replenishment in sub-Saharan Africa: new techniques and the spread of their use on farms. Agrofor. Today, 10 (2), 3-8.

31) Rosenzweig, C and Hillel, D. (1998): Climate change and global harvest. Potential impacts of the greenhouse effect on agriculture. Oxford University Press, London, 324 p.

32) Rutunga, V., Karanja, N. K., Gachene, C. K. K. and Palm, C. A.(1999): Biomass production and nutrient accumulation by *Tephrosia vogelii* and *Tithonia diversifolia* fallows during six month growth at Maseno. Biotech. Agron. Soc. Environ. 3, 237-246.

33) Sanchez, P. A. (1995): Science in agroforestry. Agrofor. Syst. 30, 5-55.

34) Sanchez, P. A., Buresh, R. J. and Leakey, R. R. S. (1997): Trees, soils and food security. Philosophical transactions of the Royal Society of London, Series B, 353, 949-961.

35) Sanchez, P. A. (2000): Linking climate change research with food security and poverty reduction in the torpics. Agric. Ecosys. Environ. 82, 371-383.

36) Sanchez, P. A., Fisher, M., Izac, A. -M. and Sheehy, J. (2000a): Linking carbon removals with food security and poverty reduction in developing countries: A plan of action. Side event briefing, 13th Meeting of the Subsidiary Bodies, UN Framework Convention on Climate Change, Lyon, France: ICRAF, Nairobi, Kenya, 8 p.

37) Sanchez, P. A., Jama, B. A., Niang, A. I. and Palm, C. A. (2000b): Soil fertility, small-farm intensification and the environment in Africa. In Tradeoffs or Synergies?, D. R. Lee and C. B. Barrett (eds.): CAB International, Wallingford, UK, pp. 327-346.

38) Sanchez, P. A. and Jama, B. A. (2001): Soil fertility replenishment takes off in East and Southern Africa. Keynote address, International Symposium on Balanced Nutrient Management Systems for the Moist Savanna and Humid Forest Zones of Africa. Cotonou, Benin, October 9, 2000: CAB International, Wallingford, UK. (in review).

39) Simons, A. J., Dawson, I. K., Duguma, B. and Tchoundjeu, Z. (1998): Passing problems: prostate and prunus. The Herbalist 43, 49-53.

40) TAC (2000): A food-secure world for all: Toward a new vision and strategy for the CGIAR: Consultative Group on International Agricultural Research, World Bank, Washington, D.C., 26 p.

41) Toure, M. (2000): A proposal for accelerating the Soil Fertility Initiative and establishment a core funding mechanism. Africa Division, World Bank, Washington, D.C., 9 p.

42) Wamuongo, J. and Jama, B. A. (2000): Proceedings of soil fertility initiative field workshop in Kenya and Uganda held at the Kenya Agricultural Research Institute (KARI) and ICRAF, 12-16 July 1999: KARI, Nairobi, Kenya.

43) Watson, R. T., Noble, I. R., Bolin, B., Ravindranath, N. H., Verardo, D. J. and Dokken, D. J. (eds.): Land use, land use change and forestry. Intergovernmental Panel on Climate Change, Cambridge University Press, UK.