INTERNATIONAL FOOD
POLICY RESEARCH INSTITUTE
sustainable solutions for ending hunger and poverty
Supported by the CGIAR

IFPRI Discussion Paper 00914

November 2009

Agroenvironmental Transformation in the Sahel

Another Kind of "Green Revolution"

Chris Reij
Gray Tappan
Melinda Smale

2020 Vision Initiative

This paper has been prepared for the project on
Millions Fed: Proven Successes in Agricultural Development
(www.ifpri.org/millionsfed)

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI) was established in 1975. IFPRI is one of 15 agricultural research centers that receive principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR).

FINANCIAL CONTRIBUTORS AND PARTNERS

IFPRI's research, capacity strengthening, and communications work is made possible by its financial contributors and partners. IFPRI receives its principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR). IFPRI gratefully acknowledges the generous unrestricted funding from Australia, Canada, China, Finland, France, Germany, India, Ireland, Italy, Japan, Netherlands, Norway, South Africa, Sweden, Switzerland, United Kingdom, United States, and World Bank.

MILLIONS FED

"Millions Fed: Proven Successes in Agricultural Development" is a project led by IFPRI and its 2020 Vision Initiative to identify interventions in agricultural development that have substantially reduced hunger and poverty; to document evidence about where, when, and why these interventions succeeded; to learn about the key drivers and factors underlying success; and to share lessons to help inform better policy and investment decisions in the future.

A total of 20 case studies are included in this project, each one based on a synthesis of the peer-reviewed literature, along with other relevant knowledge, that documents an intervention's impact on hunger and malnutrition and the pathways to food security. All these studies were in turn peer reviewed by both the Millions Fed project and IFPRI's independent Publications Review Committee.

AUTHORS

Chris Reij, Vrije Universiteit Amsterdam, the Netherlands
Fellow, Center for International Cooperation
Email: c.reij@chello.nl

Gray Tappan, U.S. Geological Survey
Physical Geographer, EROS Center
Email: tappan@usgs.gov

Melinda Smale, Oxfam America
Senior Researcher, Agriculture and Trade
Email: msmale@OxfamAmerica.org

Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

Contents

List of Tables

List of Figures

List of Boxes

ABSTRACT

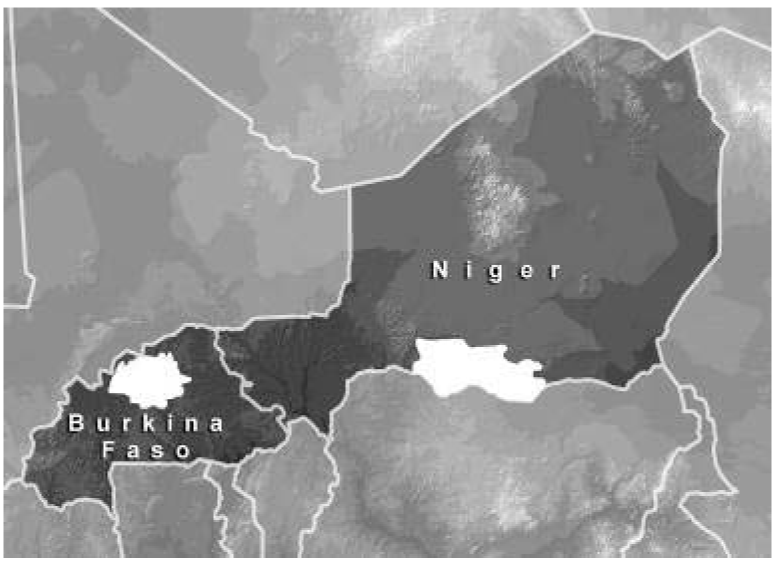
A farmer-managed, agroenvironmental transformation has occurred over the past three decades in the West African Sahel, enabling both land rehabilitation and agricultural intensification to support a dense and growing population. This paper traces the technical and institutional innovations, their impacts, and lessons learned from two successful examples. The first is the story of the improvement and replication of indigenous soil and water conservation practices across the Central Plateau of Burkina Faso. Rehabilitation of at least 200,000 hectares of degraded land enabled farmers to grow cereals on land that had been barren and intensify production through developing agroforestry systems. Additionally, rehabilitation appears to have recharged local wells. The second example is a farmer-managed process of natural regeneration, using improved, local agroforestry practices over an estimated 5 million hectares in southern Niger. This large-scale effort reduced wind erosion and increased the production and marketing of crops, fodder, firewood, fruit, and other products. In both cases, income opportunities were created, reducing incentives for migration. Women benefited from the improved supply of water, fuelwood, and other tree products. Human, social, and political capital was strengthened in a process of farmer-driven change. Fluid coalitions of actors expanded the scale of the transformation. These stories have important lessons for those who seek to create effective agricultural development partnerships and meet the challenges of climate change and food security.

Keywords: Millions Fed, Food Security, Sahel, Zai, Stone Bunds, Agroforestry, Soil Management

1. INTRODUCTION

This paper analyzes two agroenvironmental success stories in the West African Sahel. The first is the relatively well-documented story of farmer-managed soil and water conservation, which led to the rehabilitation of degraded land on a significant scale in the densely populated Central Plateau of Burkina Faso after the devastating droughts of the 1970s and 1980s. Land rehabilitation made it possible for farmers to develop agroforestry systems on land where previously few or no trees were found, extending their farm area and intensifying their production. The second is the still incompletely documented story of farmer-managed restoration of agroforestry parklands in heavily populated parts of Niger. This process began in the mid-1980s, and it may well have become one of the largest scale agroenvironmental transformations in Africa. This more recently uncovered process is substantiated here by use of aerial photography and satellite imagery. The white patches in Figure 1 show the locations of the two focus areas: the Central Plateau in Burkina Faso and the agricultural plains of southern Niger.

Figure 1. Location of two focus areas



The Sahelian "Green Revolution" began in scattered villages, where farmers' practices were rediscovered and enhanced in simple, low-cost ways. Compared with Asia's Green Revolution, this was "barefoot science" (Harrison 1987). As in Asia's Green Revolution, however, an evolving coalition of local, national, and international organizations enabled large-scale diffusion and continued use of improved practices that benefited farmers. In some instances, outsiders played pivotal roles by facilitating the exchange of knowledge, furnishing needed start-up capital, or removing technical constraints. Table 1 provides a general summary of the impacts of land rehabilitation in the two focus regions.

Table 1. Summary table of impacts of land rehabilitation on the Central Plateau of Burkina Faso and farmer-managed natural regeneration in Niger: Orders of magnitude

Indicator	Land rehabilitation in Central Plateau, Burkina Faso	Farmer-managed natural regeneration in Niger
Area concerned	200,000 to 300,000 ha	5,000,000 ha
Average costs/ha	US$200 (project costs plus labor investment by farm families)	US$20 (household labor spent on protection)
Changes in crop yields	+ 400 kg/ha	+ 100 kg/ha
Additional cereal production/year	80,000 to 120,000 tons	500,000 tons
Impact on food security (annual per capita cereal requirements of 200 kg/ha	0.4 to 0.6 million people (population of 14.8 million in 2007)	2.5 million people (population of 14.2 million in 2007)
Number of farm households involved	140,000 to 200,000	1.25 million
Impact on local groundwater recharge	5 meters or more	. . .
Increase in number of on-farm trees	Significant, but no reliable estimate	Over 200 million (all age classes)
Average volume of wood (m^3/ha)	15 m^3/ha without SWC and 28 m^3/ha with SWC	. . .
Average above ground biomass (tons/ha)	--	4.5 tons/ha (study area southeast of Zinder)

Source: Authors.
Note: SWC is soil and water conservation.

The best evidence of the economic viability of innovations on farms is the fact that they were sustainably adopted by numerous farming communities in Burkina Faso and Niger. Much of the early documentation of the Burkina Faso story, in particular, was generated by field technicians and project staff before recent advances in statistical approaches for assessing and attributing impacts. Use of aerial photography, and the sheer breadth and longevity of this initiative, attest to its success. By contrast, the scale of the Niger story has only recently been "discovered" through the use of aerial photography and satellite imagery. In neither case were all indicators of success measured with scientific rigor; some were based on farmers' statements and perceptions, and others may not have controlled sufficiently for intervening factors. This is unavoidable given the range of impacts generated by soil, water, and agroforestry conservation and the challenges of measuring them on a large geographical scale over three decades. The magnitude of the aggregate benefits over time (and in years to come) is likely to be great, especially when compared with the public funds (donor and national) that were spent to support diffusion of the innovations. Farmers themselves, as well as local and international nongovernmental organizations, bore a substantial share of total investment costs.

Section 2 characterizes the agroenvironmental situation in Burkina Faso and in Niger around 1980, which had dire social and economic consequences. Section 3 defines the technical innovations that occurred. The actors involved in the diffusion of the technical innovations and their respective roles are profiled in Section 4. The estimated scale of adoption is presented in Section 5, followed by analyses of impacts and sustainability in Sections 6 and 7. Lessons are drawn and recommendations proposed in Section 8. Appendix A explains why the extent of the transformation in Niger was not recognized for so long. Appendix B provides details about the remote sensing methodology.

2. THE SAHELIAN SITUATION AROUND 1980

The Sahel has long been plagued by droughts. The major droughts of the 20th century occurred during 1910–14 (Aubréville 1949), 1942–49, 1968–73, and 1982–84. This last "signature" drought was followed by persistent dryness through 1993. More rain fell during the decade from 1994 to 2003, but conditions remained far drier than the period from 1930 to 1965 (Anyamba and Tucker 2005).

The realities of climate change have been much more severe than is indicated by decreased amounts of precipitation. The 1968–73 drought, in particular, caused the death of many people. Large numbers of animals and trees also died, perhaps in part because farmers and herders had "forgotten" how to cope with drought. An acute human and environmental crisis ensued, exemplified by the accounts of farmers and researchers in the densely populated Yatenga Province on the northern Central Plateau of Burkina Faso.

The widespread labor migration of men in search of income caused social disruption (Monimart 1989). Between 1975 and 1985, some villages lost up to 25 percent of their families, who migrated to the Ivory Coast and to areas of higher rainfall in Burkina Faso. In the early 1980s, groundwater levels in the Central Plateau dropped an estimated 50–100 centimeters (cm) per year (Reij 1983). Many wells and boreholes went dry just after the end of the rainy season and had to be deepened. For example, "…in 1980, all wells in the village of Rissiam fell dry by the end of the rainy season, and women had to walk 8 kilometers (km) to fetch water. Some women could not cope and left their families" (Reij, Tappan, and Belemvire 2005). Average sorghum and millet yields decreased to slightly below 300 kilograms per hectare (kg/ha), as shown by several studies (Matlon and Spencer 1984; Matlon 1990; Dugue 1989). As a result, a majority of farm households had annual food deficits of 50 percent or more (Broekhuyse 1983).

Meanwhile, the surface of barren land on the Central Plateau expanded inexorably. Due to high population densities (50 persons per km^2 and more), most land was cultivated permanently, agriculture extended over land unsuitable to agriculture, and most cultivated soils were lateritic and had low natural fertility. Neither inorganic nor organic fertilizers were used in quantities that were adequate to maintain soil fertility. Empty, encrusted fields called *zipélé* stretched across significant parts of Yatenga Province. Around 1980, the French geographer Marchal (1985) described the decreasing productivity of cultivated land, the destruction of vegetation, and the expansion of cultivated land across soils that were marginal to agriculture: "…forests have disappeared; what is left is nothing more than bushes on stony hillocks, which are used as forage by herds of goats and sheep as well as by people for firewood purposes". [1] Useful tree species were lost, and little natural regeneration occurred.

Similarly, the French anthropologist Raynaut described the imbalance between humans and environment in Niger's Maradi Region at that time. Crop yields were declining, while land under cultivation expanded at a similar rate to the size of the population. The landscape was denuded and exposed to severe wind erosion. The agroenvironment and the people it sustained were increasingly vulnerable to drought (Raynaut 1987; 1997). The sense of crisis in Niger was aggravated by the fact that, in response to the above-average rainfall of the 1950–68 period, Hausa farmers had moved northward from the already densely populated southern fringes of Niger's Maradi and Zinder regions to settle in lands that were officially reserved for pastoral communities. Suddenly, these farmers could hope to harvest enough to feed their families in only one year out of five. Farmers said, "…we had to fight the Sahara"—meaning the sand and dust storms that damaged their crops and health (Larwanou, Abdoulaye, and Reij 2006).

There is little doubt that around 1980, agroenvironmental trends in the Sahel were devastating, weakening the social fabric. Something had to be done to reverse them. For many farmers, the choice was simple: claim back their land from the encroaching desert and intensify agricultural production or lay down their hoes and leave.

[1] Also see Marchal 1977.

3. THE TECHNICAL INNOVATIONS

Soil and Water Conservation in the Central Plateau of Burkina Faso

Not much was achieved in soil and water conservation on the Central Plateau of Burkina Faso before 1980. Two major projects had been implemented. The first was the so-called GERES (*Groupement Européen de Restauration des Sols)* project in the Yatenga Region, which used machinery to construct earthen bunds [2] over entire catchments. Between 1962 and 1965, this project treated 120,000 ha "by the book." That is, the treatment of watersheds began on the highest points of the slopes and gradually worked downward. Because the project was conceived without their involvement, farmers did not maintain the earthen bunds and sometimes deliberately destroyed them (Marchal 1979). The GERES project stopped prematurely in 1965. Not until 1977 did the Rural Development Fund, funded by multiple donors, begin once again to construct graded earthen bunds to reduce erosion. These were laid out in small blocks of cultivated village fields (30–60 ha). However, in this case, farmers destroyed or breached the earthen bunds because the bunds prevented water runoff from entering their fields and nourishing their crops (Reij 1983). Farmers recognized that in years of low rainfall additional water was needed for the crops to succeed. In fact, the conservation technique chosen by the Rural Development Fund was meant to fight erosion and not to harvest surface water. An estimated 60,000 ha of cultivated land was treated with graded earthen bunds (Sanders, Nagy, and Ramaswamy 1990), but within three years most of these bunds had disappeared.

It took the local farmers themselves, with initial support from nongovernmental organization (NGO) technicians, to find conservation strategies that would gain popularity. During the first half of the 1980s, they achieved two major technical advances based on indigenous soil and water conservation practices.[3] These are described next.

Improved Planting Pits (Zaï)

Around 1980, several farmers close to Ouahigouya, the capital of Yatenga, began "innovating out of despair" by experimenting with planting pits, a technique practiced for many years by farmers elsewhere in the Sahel (Reij, Tappan, and Belemvire 2005). The innovation was, first, to increase the depth and diameter of the pits, and second, to concentrate nutrients and moisture in the pits. To reclaim severely degraded farmland that was otherwise impermeable to water, farmers dug a grid of planting pits across their rock-hard plots and then added organic matter to the bottom of the basins (Ouedraogo and Sawadogo 2001; Kaboré and Reij 2004). Figure 2 shows improved planting pits with manure ready to be deposited in the pits.

---

[2] Earthern bunds are dikes constructed along the contour lines of slopes, designed to control runoff and spread water across the fields for better moisture retention. These contrast with stone bunds, described below.

[3] There were other innovations in the early 1980s, such as the level, permeable rock dams developed by French volunteers to control and reclaim gullies. This technique was mainly used in the Bam Province and will not be discussed here. Half moons, or *démi-lunes,* were also tested by the Oxfam-funded agroforestry project but did not gain immediate popularity. These were promoted during the last decade by a project funded by the International Fund for Agricultural Development (IFAD), and they are now increasingly used by farmers.

Figure 2. Improved planting pits (*zai*)

Notes: Farmers who rehabilitate degraded land with *zaï* also improve soil fertility management, enabling more intensive cereal production and agroforestry practices.

Planting pits improve soil fertility in several ways. They capture windblown soil and organic matter. The compost attracts termites, which dig channels that enhance soil architecture, water infiltration, and retention. By digesting the organic matter, the termites make nutrients more easily available to the plant roots (Ouedraogo and Sawadogo 2001). Manure (for nitrogen) and urea may be added, along with mineral fertilizer to treat the low phosphorus and potassium of these soils.

Kaboré and Reij (2004) summarize some less obvious advantages of planting pits. Rehabilitating land enables farmers to expand the size of their farms where nothing grew before—crop yields are 0 kg/ha without them, 300–400 kg/ha in a year of low rainfall, and "easily" 1,500 kg/ha in a good year. Water retained in the pits enables plants to survive long dry spells or dry spells after the first planting rains, when plants would die or fail to germinate on other plots. Because more water is harvested and conserved and organic matter is used in the pits, conditions are improved for using mineral fertilizer to increase yields and biomass production. Concentrating manure and mineral fertilizers in the pits can also be cost-effective. In the first few years, fields reclaimed with planting pits are hardly infested by *Striga* and other weeds, reducing the amount of labor needed to weed relative to other fields. Since land is prepared during the dry season, farmers do not need to wait until the rains arrive to plow their land. Some practice dry seeding.

There is no standardized approach to preparing planting pits, which is one reason why quantifying their impacts is difficult. Famers have adapted pits to meet their own needs (Hien and Ouedraogo 2001). The number of pits per hectare and the pit dimensions vary, as well as the quantity of organic matter transferred to the planting pits. Planting pits may be used to intensify cereal production, produce trees and tree products, or both. Trees and shrubs start to grow spontaneously from the seeds in the manure and compost placed in the pits, and farmers protect these in order to develop new agroforestry systems on their farms. Some farmers even sow the seeds of tree species they would like to have in their fields, using *zaï* for reforestation.

Contour Stone Bunds

Partly because of the failure of earthen bunds promoted by the Rural Development Fund, some NGOs began experimenting with soil and water conservation techniques. In the early 1980s, farmers helped shift the design of Oxfam's agroforestry project (PAF) in the Yatenga Region by prioritizing food production rather than planting trees. Farmers and the project staff then set to work on contour stone bunds. The efficiency of traditional stone lines was limited principally because contours were not accurately measured and other construction details such as stone placement and line spacing needed improvement. Aside from questions of spacing, breadth, and depth, the key was the development of a simple hosepipe water level that costs 6 US dollars[4] to make. The level could be mastered by farmers with no reading or writing skills in a day or two and ensured correct alignment along the contours (an imaginary line that runs along land of equal height above sea level) (Wright 1985).

After testing the technique during the 1979–82 period, contour stone bunds became the focus of the PAF project from 1982. The traditional technique of stone lines was reintroduced along contours. The new design allowed runoff to spread evenly through the field and trickle through the small gaps between the stones, trapping sediments and organic matter from the catchment area, including eroded soil, bits of dead plants, and manure behind the bunds, which improved the soil. Figure 3 shows a contour stone bund, which induces water to infiltrate by controlling runoff water. Before the introduction of contour stone bunds, much of the manure applied by farmers washed away during the first planting rain, but stone contour lines help retain it on fields. Critchley (1991) and Atampugre (1993) provide details and insightful reviews of early efforts in this well-known, successful project, referring to the bunds as the "Magic Stones."

Figure 3. Contour stone bunds

Notes: Contour stone bunds slow runoff, increasing infiltration and water available to crops.

[4] In this paper, all dollars ($) are U.S. dollars.

Farmer-Managed Natural Regeneration in Southern Niger

In contrast to forestry plantations that had been promoted previously in the Sahel, farmer-managed natural regeneration FMNR "adapts centuries-old methods of woodland management to produce continuous harvests of trees for fuel, building materials, food and fodder without the need for frequent, costly replanting" (WRI 2008). The only technical innovation was that farmers, with the help of new techniques, were once again protecting and managing the regeneration of native trees and shrubs among their crops (Larwanou, Abdoulaye, and Reij 2006).

Farmers use four steps to produce parklands (WRI 2008). First, when they clear land to plant crops, they select tree stumps from among the mature root systems in the field, based on the usefulness of the species for food (nutritious fruits and leaves), fuel, or fodder. The products of most of these species also have commercial value, which means that what is not used by a family for their own needs can also be sold on the market. Next, farmers select the tallest and straightest stems to prune and protect on each stump. Third, they remove the unwanted stems and side branches. Finally, farmers remove new stems and prune surplus side branches. The original model, developed by Tony Rinaudo of Serving in Mission (SIM, formerly the Society of International Ministries) in Niger during the 1970s and 1980s, involved harvesting one of the original five stems every year, with a newly sprouting stem chosen as a replacement. SIM then launched the Maradi Integrated Development Project with this component as a feature (WRI 2008). Farmers adapted techniques to their own situation and objectives. Some farmers created woodlands by regrowing many more stems per stump, sometimes allowing more than 200 stumps per ha to regenerate (WRI 2008). Figure 4 shows an example of high-density FMNR.

Three factors determine which tree species regenerate: (1) the stumps and roots present in the field, which sprout; (2) the seeds of trees and bushes in the "seed memory" of the soil (seeds that remain dormant until rainfall or another event allows them to grow); and (3) seeds present in livestock manure and bird droppings.

Figure 4. High-density FMNR in southern Zinder dominated by *Faidherbia albida* (February 2006)

Larwanou, Abdoulaye, and Reij (2006) interviewed about 400 farmers in the Zinder Region individually and in groups about FMNR. According to the farmers interviewed, the trees generate multiple benefits. First, they reduce wind speed and evaporation. In the 1980s, crops had to be replanted three or four times because they were covered by wind-blown sand, but today farmers typically plant only once. Trees produce at least a six-month supply of fodder for on-farm livestock. Firewood, fruit, and medicinal products are supplied by trees for home consumption or cash sales. Nitrogen-fixing species like *Faidherbia albida* enhance soil fertility, although farmers do not observe these effects with very young trees.

The most common species regenerating naturally and protected by farmers in Niger include *Faidherbia albida* (winter thorn, commonly known as *gao* in Niger), *Combretum glutinosum, Guiera senegalensis, Piliostigma reticulatum* (camel's foot), and *Bauhinia rufescens*. Depending on the location of the village, other species can be important, such as *Adansonia digitata* (baobab) and *Prosopis africana* (ironwood).

4. THE INNOVATORS

All three technical innovations were the result of experimentation by farmers (improved traditional planting pits) or by NGO technicians (contour stone bunds, FMNR). Scientists validated the techniques and evaluated their impacts. Scaling up technical innovations from scattered villages to regions required institutional and organizational innovations, as well as numerous actors, highlighted in this section.

Charismatic leaders, both farmers and development agents, played key roles in diffusing the innovations. In Burkina Faso, private extension efforts by lead farmers such as those described in Box 1 substituted to some extent for the public extension service, which had become crippled by structural adjustment programs and which had increasingly concentrated their limited activities in cotton-growing regions (Haggblade and Hazell 2009).

Ouedraogo and Sawadogo (2001) describe three models for disseminating planting pits, each spearheaded by an individual farmer.[5] Since 1984, Yacouba Sawadogo has organized two market days per year to promote planting pits. In the first, after the harvest, farmers bring a sample of the crop varieties they cultivated in their *zaï*. Yacouba stores the seeds on his farm. On the second day, just before planting, farmers select the seed they want to plant that season. Each market day has a specific theme and a display of tools used to dig *zaï*. Open-air, weekly fairs held in Sahelian villages are important nodes of farmer social and economic interaction. Initially small, by 2000, Yacouba's market days involved farmers from more than 100 villages.

In 1992, Ousseni Zoromé began a *zaï* school. He trained some local farmers on a gravelly site next to the road. When the crop grew, the effort attracted the attention of the Minister of Agriculture. By 2001, there were over 20 schools and 1,000 members of his network, each group charged with the rehabilitation of a piece of degraded land. This approach is similar to the adult education, "Farmer Field School" method so successfully used to disseminate integrated pest management practices in Asia and now promoted for a range of development purposes.

A third approach is the teacher-student model. Ali Ouedraogo trained individual farmers in villages around Gourcy and visited them regularly to work with them directly in their fields and exchange ideas. His students trained other farmers in improved *zaï* techniques. Some of the students then experimented with their own techniques. Ouedraogo and Sawadogo (2001) wrote that "…these innovative farmers do not want to monopolize their knowledge. They are generous in sharing their experience with others and their benefits are primarily in the form of personal satisfaction and higher social recognition. These appear to have been their main motivations to develop their own extension models for giving practical training and advice to other farmers who, in turn, are keen to learn from them."

A charismatic leader in FMNR is Tony Rinaudo, the Christian missionary mentioned earlier. In 1958, SIM had established a farm school in Maradi. After the droughts, SIM and other organizations in Maradi shifted their attention to trees, but efforts were limited. In 1983, Rinaudo recognized the underground forests of stumps and roots in the fields of farmers and that these could be regenerated at a fraction of the cost of growing nursery tree stock. Knowing the value of trees to farmers, during the droughts of 1984 and 1985, he offered food to farmers in return for protecting on-farm natural regeneration. Many farmers immediately did so, but when food aid stopped, few continued to protect and manage the trees. Soon, those who had cut their trees began to regret their actions when they observed the multiple benefits of FMNR. FMNR spread spontaneously as farmers heard about the technique, and projects organized study visits for staff and for farmers to the Maradi Region.

During these decades, the commitment of NGOs and other stakeholders to building human capital through adult education and encouraging farmer-to-farmer learning was fundamental for change

[5] The three models of private extension functioned for some years and then stopped functioning. Reasons behind this were age, lack of means, or inability of many farmers to adequately master the technique.

(Critchley 1991; Reij and Smaling 2007; Tappan and McGahuey 2007). On-farm research and training in basic skills were part of innovation and replication.

In part because these innovations often require collective action, farmer groups and village associations of various types were instrumental in what became known as a "movement." Planting pits and trees can be managed on land over which farmers have exclusive property rights, but larger works such as permeable dams and terraces that affect multiple farms depend on collective action to organize labor for construction and maintenance and to allocate use rights and responsibilities. Whether or not collective action was necessary for the investment, it was needed to allocate fields for technical experimentation and negotiate use rights.

In the process, social capital was strengthened. Renovation of traditional work groups in Yatenga Province is detailed by Ouedraogo (1990) and summarized by Smale and Ruttan (1994). Tougiani, Guero, and Rinaudo (2009) describe a similar pattern in Aguié, Niger, undertaken by the Desert Community Initiative. New governance structures, which included marginalized social groups, were created to support community monitoring and management of land and tree regeneration.

Farming communities developed political capital to attract investments from donors or from the state by way of study tours, tools, subsidized transport of stones, and food-for-work for the poorest. Successful replication of each successful innovation was the result of a confluence of efforts by individual farmers, farmer groups, local NGOs like the Groupements Naams, international NGOs like Oxfam, and bilateral and multilateral donors supported by national governments. The plethora of institutions involved illustrates the development of "bridging" capital, which enables local communities to link in constructive ways to national and international institutions. Linkages and compatibility among institutions have been crucial.

Since the middle of the 1980s, all major donors and projects in Burkina Faso have promoted contour stone bunds or *zaï* or both. Building on the soil and water conservation innovations in the Yatenga Province, a major Dutch-funded regional development project was implemented in the Kaya Region (1982–2000), the German-funded PATECORE project was conducted in Bam Province (1989–2004), and an IFAD-funded project intervened in several provinces from 1989 to 2003 (Reij and Steeds 2003). Other projects were funded by the Netherlands and the World Bank. At the request of the Burkina Faso government, many NGOs intervened in the northern part of the Central Plateau because it was one of the poorest regions of the country and the most degraded (Reij, Tappan, and Belemvire 2005). In Niger, the widespread adoption of FMNR was facilitated by a similar configuration of actors (WRI 2008). In Maradi, in addition to SIM and the Maradi Integrated Development Project, an IFAD project in Aguié made FMNR a priority action (Larwanou, Abdoulaye, and Reij 2006).

Government policy and supporting public investments were also important. Reij and Steeds (2003) note the strong push by the Burkinabé government from the mid-1980s to increase awareness of environmental problems and their solutions and sound macroeconomic management that did not discriminate against agriculture and natural resources, including 50 percent devaluation of the West African currency in January 1994, which stimulated exports. Major roads linking the capital of Ouagadougou and the two regional capitals of Ouahigouya and Kaya reduced transport costs and supported commercialization of farm and tree products (Reij, Tappan, and Belemvire 2005). Trunk roads that reduced costs for traders in Ivory Coast, Ghana, and Nigeria to buy sesame, cowpeas, and vegetables from the Central Plateau stimulated the local economy (Reij and Smaling 2007). A study by Kazianga and Masters (2002) on the determinants of investments in SWC technologies in Burkina Faso shows that these investments responded to two policy-influenced variables. The first was the degree to which farmers own their land securely and the second was the degree to which farmers manage their livestock intensively. Reij, Tappan and Belemvire (2005) have drawn similar conclusions based on a study they implemented in 2002.

In the case of FMNR, guaranteeing rights of access to the farmer who regenerates the trees on farms appears to have been crucial, but widespread diffusion occurred before official reform once farmers began to perceive that the trees and tree products on their fields were their own. In the words of Michael McGahuey, "proof of concept preceded policy change, and proof of concept came with the sweat of farmers and the technicians who worked alongside them" (personal communication, September 22, 2009). The underlying reasons for changes in farmers' perceptions are not entirely clear. In 1985, the general perception was that all the natural resources, including the trees, belonged to the State, but after 1985 the State weakened considerably due to an economic and political crisis that lasted at least 15 years. After 1985, farmers considered the trees in their fields as their own (Larwanou, Abdoulaye, and Reij 2006). National policy also provided incentives for change by involving rural people more in development activities and informing them about the ecological crisis. Eventually, farmers' efforts, the dedication of national and international scientists, and policy dialogue effectively supported by the Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS), led to the official reform of forestry policy (Alhousseni Bretaudeau, Michael McGahuey, and John Lewis, personal communication, July 2009).

Box 1. Farmer innovators in land rehabilitation and agroforestry

In 1979, Yacouba Sawadogo started to use the *zaï* technique to rehabilitate degraded land. At that time, his main aim was to produce more sorghum and millet. By digging deeper and wider pits during the dry season and by adding manure, he managed to reclaim land and achieve food self-sufficiency. He noticed that tree species started to grow spontaneously in the pits and began to protect them. Each year, he placed the seeds of desired tree species in the pits and alongside the contour bunds he had also constructed. Within a few years, the piece of barren land was gradually transformed into a 12-ha forest with many different species. When Yacouba started rehabilitating his land, he counted trees of only four species; 20 years later, he counts more than 60 species on his fields. He has also introduced some medicinal species. Today he produces more than enough food to feed his family. He aims to create a multipurpose forest of 20 ha, investing more in growing medicinal woody plants and introducing fauna into his forest. "What motivates Yacouba Sawadogo? He says that he wants to prove that environmental degradation is not irreversible and that it is possible to make a living in the Yatenga Region. At the same time, he wants to be recognized as an innovator and this public recognition is a major incentive to him" (Ouedraogo and Sawadogo, 2001).

Namwaya Sawadogo is known as the "ecologist" of Sanmatenga Province in Burkina Faso. Namwaya was born in 1943. By 2000, he supported 20 family members on a farm of 14 ha—almost three times the average size in his area. When he began, he was an itinerant trader who had 1 ha of degraded land that would not feed his family. Namwaya has made many innovations in crop production. In 1988, he started to construct stone bunds along the contours of his poor land, planting perennial grass alongside them. Through a local association to which he belonged, he bought a donkey cart on credit, primarily to transport the stones. He applied mulch to his barren land, and in 1991, he began using a compost pit. In 1995, Namwaya visited the Yatenga Region and decided to dig planting pits. Two years later, in a serious drought, he was the only farmer in his village who could feed his family (Taonda, Hien, and Zango 2001).

Namwaya also innovated in agroforestry. In 1990, he accepted the offer of the government forestry agents for training in tree nursery establishment, planting one next to a nearby government-built dam. He works with exotic and local seedlings and those that can be multiplied through root suckers. He sows nitrogen-fixing annual crops such as groundnuts between the lines of eucalyptus or uses this space for grazing, lightly scarifying the surface to improve the growing conditions for grasses. In 1997 he participated in a study visit to Niger where he picked up the idea to use the pods of *Piliostigma reticulatum* (camel's foot) as a source of fodder. Since then, he has systematically protected and managed *Piliostigma* on his fields and his neighbors have followed his example. "When assessing the impact of innovations on his life, Namwaya speaks in terms of his gain in respectability, responsibility, and popularity, but also his increased financial capacity and his ability to support those in need" (Taonda, Hien, and Zango 2001).

Box 1. Continued

The rehabilitation of land and the reconstitution of the woody vegetation have greatly increased the social status of the farmer innovators, whose reputation extends beyond their provinces and the borders of Burkina Faso. The cases illustrate that, as a result of indigenous innovation and initiative, it is possible to produce a considerable and diverse plant biomass than can be used for many purposes, including fodder, within a fairly short time span of 5–10 years. This facilitates the integration of livestock keeping and cropping systems, which is the basis of sustainable agricultural intensification.

5. THE SCALE OF ADOPTION

Stone Bunds and *Zaï*

By 2001, well over 100,000 ha of strongly degraded land had been rehabilitated by projects and farmers on the northern part of the Central Plateau alone (Reij and Thiombiano 2003). Taking into account what has been achieved in this region since then and on other parts of the Central Plateau, it is likely that the total area rehabilitated over the past three decades is somewhere between 200,000 and 300,000 ha (Botoni and Reij 2009). A recent study shows that in villages with a long history of soil and water conservation, 72 to 94 percent of the cultivated land has been rehabilitated with one or more conservation techniques. In villages with a shorter history, this percentage ranges from 9 to 43 percent (Belemviré et al. 2008).

FMNR

A SIM evaluation in 1999 suggested that in the project zone alone, 88 percent of farmers surveyed practiced FMNR in one way or another in their fields, with an estimated 1.25 million trees added each year through project activities (Larwanou, Abdoulaye, and Reij 2006). In the three districts of Zinder they surveyed, Larwanou, Abdoulaye, and Reij (2006) estimated an affected area of 1 million ha, with a density of 20 to 120 trees, and sometimes more, per hectare. "…Vast expanses of savanna devoid of vegetation in the early 1980s are now densely studded by trees, shrubs, and crops" (WRI 2008). Many villages now have 10 to 20 times more trees than 20 years ago. Farmers have literally "constructed" new agroforestry parklands on a massive scale.

In 2005–06, a team of Nigerien researchers examined the impacts of investments in natural resource management and long-term trends in agriculture and environment (Adam et al. 2006).[6] The team's initial field survey in the Maradi and Zinder Regions confirmed that FMNR was (1) locally significant, (2) geographically extensive, (3) an on-farm phenomenon, and (4) well correlated with the sandy ferruginous soils of the south-central agricultural plain.

More significantly, the highest tree densities were found in areas of high rural population density. Earlier research reported the protection and management of trees on farms in densely populated areas of Niger (Yamba 1995; Luxereau and Roussel 1997; Joet, Jouve, and Banion 1998; Awaïss 2000; Faye et al. 2001; Mortimore et al. 2001; Mortimore and Turner 2005; Raynaut 2002), but the team was surprised by the extent to which farmers had been protecting and managing on-farm trees since the middle of the 1980s.[7] Long transects were surveyed across the Maradi-Zinder agricultural region in 2006 and 2007, indicating that FMNR was predominant across a 300-km swath from west of Maradi to east of Mirriah. The high correlation of FMNR to the sandy ferruginous soils and areas of intensive cultivation suggests that the FMNR area can be roughly equated to the mapped boundaries of agricultural land use.

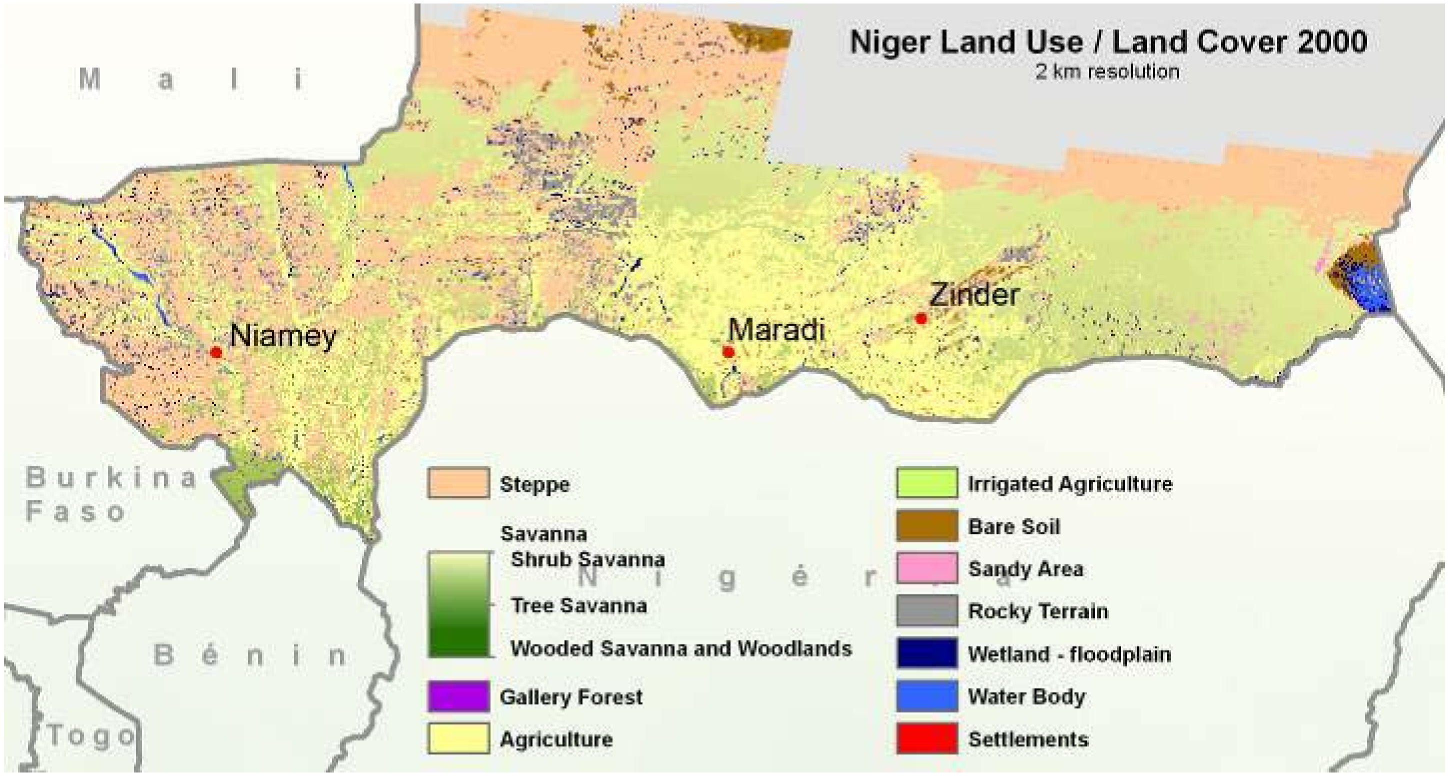
Figure 5 shows the land use and land cover of southern Niger. Field work and initial analysis of high-resolution satellite imagery indicated that the extent of FMNR was present across much of the agricultural plain that dominates the Maradi and Zinder regions. The area of this agricultural region is about 6.9 million ha. However, not all soil types found in the region are conducive to rainfed agriculture and field trees. Original estimates by the authors placed the area of FMNR at 5 million ha (about the size of Costa Rica). Recent analysis of complete high-resolution image coverage of these regions confirms the geographic area of FMNR. High resolution images acquired during the period 2003 to 2008 were

[6] This study was supported by Gray Tappan and Chris Reij and funded by Swiss Development Cooperation. Complementary funding was provided by the U.S. Agency for International Development (USAID) for remote sensing (U.S. Geological Survey, Earth Resources Observation and Science Center, South Dakota) and for specific research support by the International Resource Group.

[7] Taylor and Rands (1992) noticed that thousands of farmers in the Maradi region protected and managed natural regeneration. Rands (1996) remarked that farmer-managed natural regeneration is among the most widely spread natural resource management innovations in Niger. USAID-funded projects invested in the organization of farmer visits to the Maradi region. This helped in spreading this practice.

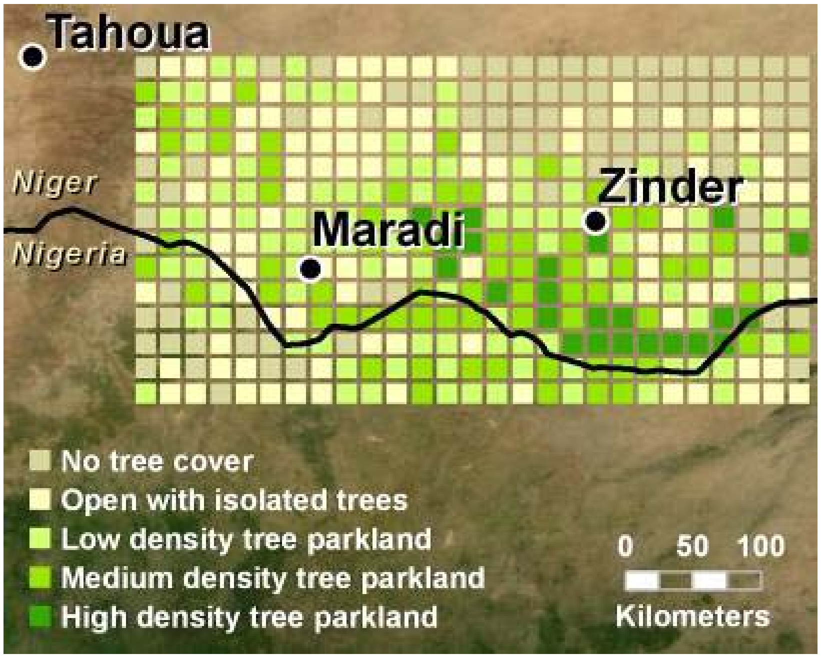
systematically sampled to establish tree densities and their extent across the entire agricultural region. Results from this analysis peg the FMNR figure at 4,828,500 ha. Figure 6 shows the patterns and extent of FMNR across the Maradi-Zinder agricultural region. FMNR is also visible in other regions (locally present in Tahoua and Dosso regions and in the northern part of the Niamey Region). Many of the trees are young, the hallmark of a recent and rapidly developing agricultural parkland still increasing in density and cover. Appendixes A and B provide more detail concerning methodology.

Figure 5. Map of the land use and land cover of Niger in 2000



Notes: This map is taken from a visual interpretation of Landsat imagery and field work. It is a collaborative effort of the U. S. Geological Survey, Earth Resources Observation and Science Center, the Direction de l'Environnement, the Institut Géographique National du Niger, and the AGRHYMET Regional Center. The main area of FMNR is located on the agricultural plain (yellow) in the Maradi and Zinder Regions.

Figure 6. Map showing the extent and density of tree cover, agricultural region, southern Niger



Notes: Tree densities were measured from a systematic sample of 378 sites distributed in a grid pattern. Tree density classes at each site are symbolized by the shaded squares. FMNR is considered to be present in the low, medium, and high density tree parklands.

6. IMPACTS

Crop Productivity

The immediate economic impacts of planting pits and contour bunds are yield gains and lower costs of labor, tools, and stones. Because water harvesting techniques like *zaï* and contour stone bunds relieve the water constraint to crop production, lands that used to be barren can produce a harvest in the first year, and if the investments are maintained well or augmented with other interventions, as was the case for the farmer innovators described in Box 1, benefits can increase over time. In particular, fields with planting pits are more likely to produce a crop in dry years and reduce the risk of crop failure.

The PAF project estimated that contour stone bunds had a positive, statistically significant impact on cereal yields (Wright 1985). At the request of the *Fonds de l'Eau et de l'Equipement Rural* (FEER),[8] Matlon (1985), at that time a research economist at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), found an average cereal yield of almost 800 kg/ha on 17 sites rehabilitated with stone bunds. This was 325 kg/ha higher than the average yield on control plots.[9] Since then, numerous researchers have measured impacts of contour stone bunds and of *zaï* on cereal yields as part of their doctoral research (Kaboré 1995; Kambou 1996; de Graaff 1996; Maatman 1999; Zombré 2003; Zougmoré 2003; Ouedraogo 2005; Sawadogo 2006). Their studies explore, for instance, the impacts of the use of organic and inorganic fertilizers, the quality of organic matter used, the spacing of contour bunds and the impact on soil humidity. All find positive impacts on cereal yields, varying from 40 percent to more than 100 percent. Most measurements are limited to one to three years only. The considerable variability of annual rainfall and other conditions (time of weeding, number of weeding rounds, quality of soil fertility management) implies that evidence is anecdotal. Nevertheless, the number of anecdotes is considerable and it can be argued that together they constitute sufficient evidence of positive impacts. The best indicator of positive impacts is, of course, that farmers continue to dig planting pits and construct stone bunds on their own initiative and without external support. They would not do so unless these investments produced tangible benefits.

Sawadogo and Ouedraogo (1996) and Sawadogo (2003; 2006; 2008) have regularly studied the impact of *zaï*, contour stone bunds, and combinations of both, along with half moons (*démi-lunes*) on cereal yields and on crop residues. In his studies, Sawadogo has examined a range of factors affecting yields, such as rainfall, soil fertility management, soil types, the position of the fields on the slope, whether fields are cultivated by the production unit or individual men or women. The social and economic status of farmers, the amount of farm equipment, and the age of the bunds are also determinants of yield.

Sawadogo's research demonstrates the complexity of measuring impacts. For example, of 700 farmers studied in 2007, 28 percent did not use manure, 54 percent used between 1 and 5 tons/ha, and 18 percent used 5–10 tons/ha. Table 2 shows that *zaï* alone usually have a bigger impact on yields than only contour stone bunds, but the combination of *zaï* and contour stone bunds or grass strips has the biggest impact on cereal yields. The "without situation" represents cereal yields in cultivated fields without soil and water conservation techniques.

---

[8] The Fund for Water and Rural Equipment, or FEER, succeeded the Rural Development Fund (FDR).

[9] In the first half of the 1980s, a team from Purdue University researched tied ridges in several villages on the Central Plateau. This research has been documented extensively (an example is Sanders and Roth [1985]). A main reason farmers never adopted tied ridges was that they require a considerable investment of labor early in the rainy season when labor is scarce. Planting pits (*zaï*) require even more labor, but this is invested mainly during the dry season when labor is less scarce.

Table 2. Impact of soil and water conservation techniques on cereal yields in four groups of villages in 2007 (kg/ha)

Village	Without Situation	*Zaï*	Yield increase	Contour stone bunds	Yield increase	Stone bunds + *zaï** or grass strips**	Yield increase
Ziga	434	772	+ 346	574	+ 130	956*	+ 522
Ranawa	376	804	+ 428	531	+ 155	922*	+ 546
Noh	486	700	+ 214	706	+ 220	980**	+ 494
Rissiam	468	716	+ 248	649	+ 181	992**	+ 524

Source: Sawadogo 2008.

The mean impacts reported in Table 2 do not reveal that one-fifth of the farmers surveyed who used at least 5 tons of manure per hectare harvested 1,000–1,250 kg/ha of grain (Sawadogo 2008). Furthermore, 2007 was a year of high but poorly distributed rainfall, leading to crop failure in many locations.

Farmers who rehabilitate land generally also invest in improved soil fertility management. This leads to a stronger integration of agriculture and livestock and even to the emergence of a market for manure and of paid work for its transport by donkey cart. The agro-pastoralist Fulani have little land and much livestock. Mossi farmers have begun buying manure from the Fulani, and they hire Fulani herders to manage their livestock (Sawadogo 2003; 2008).

In Niger, *Faidherbia albida* is highly appreciated because of its impact on soil fertility, and its pods and leaves are highly valued as a source of fodder. Boffa (1999) has presented an overview of research conducted on the improvement of soil nutrient content and crop yields under *Faidherbia albida* canopies, compared with controls in the open. Percent increases in nitrogen content ranged from 15 to 156 percent, but significant increases were also found in carbon, phosphorus, exchangeable potassium, calcium, and magnesium. Even though these increases are significant, overall soil fertility levels remain low. The impact on millet yields ranged from 49 to 153 percent increases; for sorghum, most yield increases ranged from 36 to 169 percent. In absolute terms, this means in most cases an additional cereal yield of 400 to 500 kg/ha or more. This helps explain why farmers in parts of the densely populated southern Zinder Region have created a high-density monoculture of *Faidherbia albida.*

Larwanou and Adam (2008) report significant increases in phosphorus content under *Combretum glutinosum* and *Guiera senegalensis* at a depth of 20 cm. They argue that these two species ameliorate the pronounced lack of phosphorus in cultivated soils in Niger.

Food Security

On Burkina's entire Central Plateau, at least 200,000 ha of land have been rehabilitated. Using a net average gain in cereal production of 400 kg/ha, which is conservative from a farmer's perspective, this agroenvironmental change implies an additional harvest of 80,000 tons/year.

What were the implications for household food security? In the early 1980s, more than half the farm households had a structural food deficit of 6 months or more. Although some families have become fully food secure, most families have only seen a reduction of their structural food deficits from 6 months to 2 or 3 months, which is an important gain.[10] However, farmers on the Central Plateau do not survive on agriculture alone; they have developed complex livelihood strategies in which migration plays a major role (Reardon, Matlon, and Delgado 1988).

[10] The farmer innovators mentioned in Box 1 have not had a food shortage since they began innovating in the 1980s, and some of them have built considerable security stocks. Nevertheless, they report that when crops fail they buy grain on the market just like other farmers in their communities in order not to set themselves apart. Cultural norms in these villages reinforce modesty and social awareness, especially with respect to material wealth and particularly in times of duress.

The southern parts of the Zinder and the Maradi Regions in Niger are characterized by high population densities, which vary from 80 to 150 persons/km². About 80 percent of all land is cultivated and little off-farm natural vegetation is left. Rich families cultivate on average 9 ha, but poor families cultivate 4 ha or less. If an average farm household practices FMNR on 4 ha, then FMNR involves about 1.25 million households.

FMNR has both direct and indirect impacts on household food security. Food availability is enhanced through higher crop yields on FMNR fields. It seems reasonable to assume that 1 ha of FMNR increases cereal yields on average by 100 kg, but the increase would be much higher in the case of *Faidherbia albida.*[11] This suggests that at the estimated scale of adoption—an average area rehabilitated per farm of 1.5 ha and an average household size of eight persons—FMNR contributes an additional 500,000 tons of cereals, which affects the lives of 2.5 million people (out of a total population of about 15 million inhabitants in 2009).

FMNR has an indirect impact on food security through tree crop products, which depend on the species. More fodder and crop residues on-farm allow farmers to keep more livestock closer to their fields, contributing to more intensive and remunerative livestock production. There is some evidence that the innovations supported the accumulation of another valuable asset of dryland farmers—livestock (Baoua 2006; Larwanou and Adam 2008). On Burkina's Central Plateau, farmers report that there is now sufficient fodder, stover, and water in the village, with smaller cereal deficits; therefore, they can accumulate enough cash to augment their herds. In the village of Sam, in Bam Province, the Peulh indicated that they no longer move their herds because of the abundance of crop residues and perennial grasses (Reij, Tappan, and Belemvire 2005). In turn, more livestock means more manure can be used to improve soil fertility. Twenty years ago, most manure in Southern Zinder was used as a source of cooking fuel, but now it is all restored to the fields because firewood from trees on farms has replaced manure as the key source of cooking fuel.

Time allocated to fuelwood collection by women can be reallocated to other activities, including food production and preparation and childcare. Often the sales of tree products are by young men (fuel, poles) or women (leaves, fruits), and they have lucrative local markets, reducing incentives for migration and creating multiplier effects in village economies. Larwanou and Adam (2008) mention that the earnings from the sale of baobab (*Adansonia digitata*) leaves from a single tree are worth \$24–40, depending on the size of the crown. They report that firewood sales generate revenues that range from \$6 to \$20 per year in the village of Ara Sofoua and \$30 to \$120 in the village of Gaounawa. Small businesses related to tree products, including medicinal plants, fodder, and materials for construction, have emerged (Larwanou, Abdoulaye, and Reij 2006). In Aguié, Niger, a sustainable fuelwood market has emerged (Tougiani, Guero, and Rinaudo 2008).

In poor growing seasons and during the hungry period that typically precedes harvest, as families finish their sorghum and millet stocks, the importance of some of these fruits and leaves assumes even greater significance in the local diet. Some are key sources of vitamins and micronutrients, especially during hungry periods (Savy et al. 2006).

How can these findings be reconciled with the fact that in July and August 2005 thousands of women and children stayed in nutrition centers in the Maradi and Zinder regions? Field visits between October 2005 and June 2006 confirmed that villages that had protected and managed natural regeneration had been much less affected by the food shortages than villages that had not. According to farmers interviewed by Larwanou, Abdoulaye, and Reij (2006), during drought years such as 2004–05 in Niger, parklands helped families "make ends meet" through consumption and sale of tree products. Farmers who are able to stockpile cereals during good years and to supplement cereal production with consumption and sales of tree products are better insulated against cyclical droughts, which are predicted to increase as a result of climate change (WRI 2008). In the village of Dan Saga (Aguié district), which has a long history with FMNR, there was no drought-related infant mortality in the summer of 2005,

[11] The lower figure is more realistic because *Faidherbia albida* dominates only part of the area under FMNR, and the age of the tree stock differs from village to village and from field to field.

because the pruning and cutting of trees allowed villagers to sell these products on the market and buy expensive cereals.

Since millet and sorghum make up more than 90 percent of the typical villager's diet, it was critical that in 2006 the country was able to produce 283 kg of cereal per capita, almost identical to the 285 kg produced in 1980, despite a near-doubling of the population over 25 years (WRI 2008; Wentling 2008). Assuming an average of 200 kg is needed to cover annual per capita cereal requirements, Niger managed to produce a small surplus in 2006.

Equity

Aside from land, labor is the principal factor of crop production in the Sahel and challenges are met through careful organization of family labor, shared community labor, and hired labor. It stands to reason that those Sahelian farmers who are better endowed with human, social, and financial capital are more likely to invest in labor-intensive techniques than others because they can also hire labor. Some field experience suggests that this is indeed the case especially for planting pits. Slingerland and Stork (2000) found that farmers investing in *zaï* had larger households, more means of transport and more livestock, and higher quality housing and equipment than those who did not. Poorer families are more likely to benefit from project-supported interventions that spread or retain water on blocks of land that cover the fields of multiple households simultaneously, such as project-supported stone bunds or permeable dams (Haggblade and Hazell 2009).

Without a doubt, as expressed in their own testimonies, Sahelian women have benefited tremendously from an improved supply of fuelwood and water that has resulted from these innovations over the past 20–30 years (Yamba et al. 2005; Reij and Thiombano 2003). Wives of farmer innovators in Burkina Faso stated that because the men concentrated on the *zaï* fields, the sandy soils not suitable for *zaï* have been allocated to women for groundnut and Bambara groundnut production, with positive consequences for their cash income (Sawadogo et al. 2001). Women also earned substantial annual income ($210) from the sale of leaves from regenerated baobab (*Adansonia digitata*) trees, as well as the flowers of the kapok (*Ceiba pentandra*) and fruits of shea nut (*Vitellaria paradoxa*) and locust bean (*Parkia biglobosa*).

In the three districts they studied in Zinder Department, Larwanou, Abdoulaye, and Reij (2006) found that women have free access to dead wood in the fields and to other products, such as the pods of the *gao* tree (*Faidherbia albida*) to feed livestock, and they can own trees that produce edible products, such as the baobab (*Adansonia digitata*), through inheritance or purchase. Reij, Tappan, and Belemvire (2005) mention more livestock investment by both men and women in the Central Plateau, and Larwanou, Abdoulaye, and Reij (2006) found the same in Zinder. Farmers interviewed report a stronger economic position of women involved in FMNR and a better capacity to feed their families a nutritious, diverse diet that includes more fruits, leaves, and vegetables.

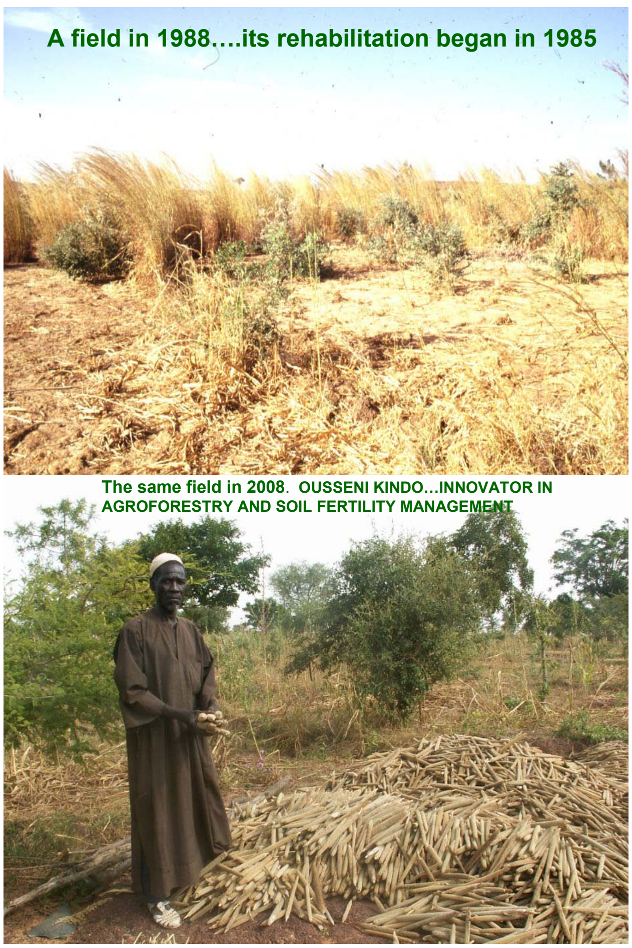
According to WRI (2008), women may in fact be the biggest winners from FMNR in Niger. Women are excluded by traditional custom from many resource management decisions. Tougiani, Guero, and Rinaudo (2008) argue that FMNR actually favors women because it requires year-round tending while many men still migrate during the dry season. Using their own wood eliminates the cost of purchasing with scarce cash, while selling wood and baobab leaves is highly remunerative. Women also invest their income in goats and sheep, which they feed with the pods of *Faidherbia albida* and at the end of the dry season with the leaves of *Guiera senegalensis*.

Agroenvironmental Impacts

Belemvire (2003) analyzed vegetation on 68 sites (47 on rehabilitated land and 21 on control plots) in 12 study villages in the northern part of the Central Plateau. He found 33 tree species on rehabilitated land, compared with 26 species on control plots. This is an important difference when one takes into account that the starting point on the rehabilitated fields was much worse than on the control plots. The dominating species on the rehabilitated plots are *Guiera senegalensis* (24 percent), *Leptadenia hastata* (12 percent), and *Balanites aegyptiaca* (12 percent). On the control plots the dominating species are *Piliostigma thonningii* (30 percent), *Guiera senegalensis* (17 percent), and *Combretum glutinosum* (9.5 percent). The average tree density (all age classes) is 126 trees/ha on rehabilitated fields and 103 trees/ha on control plots. On the control plots, 77.5 percent of the trees have a diameter of up to 4 cm. On the rehabilitated plots, this is the case for only 56 percent of the trees. Trees with bigger diameters (11 cm or more) are much better represented on the rehabilitated fields (37 percent against 17 percent on control plots).

These data confirm an increase in the number of on-farm trees on rehabilitated land and suggest that farmers have been developing agroforestry systems on what used to be barren land. Figure 7 shows the same field in October 1988 (left) and in October 2008 (right). In 1985 the field was almost completely barren (1 tree) when the farmer (Ousseni Kindo) began constructing contour stone bunds and digging *zaï*. In October 1988 perennial grasses have been planted along the contour stone bunds and some bushes are visible. In October 2008 the farmer had more than a hundred baobab trees (*Adansonia digitata*) on his field and even more other useful trees.

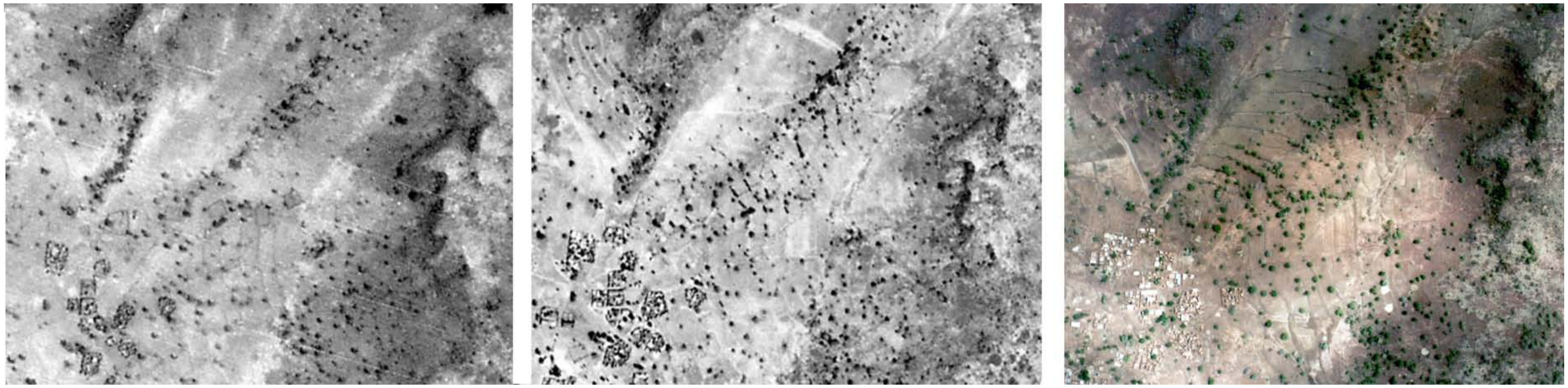
Figure 7. Increase in on-farm trees after rehabilitation using *zai* and contour stone bunds



Notes: A comparison of the same field in 1988 and in 2008 shows a significant increase in on-farm trees, which became possible after investment in land rehabilitation.

Reij, Tappan, and Belemvire (2005) compared the evolution of land use in three villages on the northern part of the Central Plateau between 1968 and 2002. Two villages have a long history of interventions in soil and water conservation (Ranawa and Rissiam) and one has not (Derhogo). In Derhogo the area covered by cultivated parkland declined dramatically from 32 percent in 1984 to 24 percent in 2002. During the same period, the two villages with interventions show increases in cultivation under open parkland and under dense parkland from around 66 percent in 1984 to about 72 percent in 2002. They used time-series remote sensing to track the land resource changes in these villages, including land rehabilitation and the impact of contour stone bunds on increasing on-farm tree cover. At Ranawa, for example, aerial photographs from 1984, 1996, and 2002 show a clear trend of increasing tree cover in association with the regular pattern of contour stone bunds (Figure 8). The surface under bare soil remains well under 10 percent in Rissiam and in Ranawa but increases in Derhogo from 41.3 to 49.4 percent of the total village territory. It should also be noted that livestock pressure is higher in Derhogo than in the other two villages.

Figure 8. Time-series aerial photographs over Ranawa in 1984, 1996, and 2002 (left to right).



Note: This series of aerial views shows the positive impact of contour stone bunds (faint linear features) on increasing on-farm tree density. Trees tend to grow from the soils and seeds trapped by the stone bunds.

Source: Authors.

The diversity of local vegetation is also supported. Because the manure and compost used in *zaï* contain seeds of trees, shrubs, and grasses, pitted fields show substantial regeneration of woody and herbaceous species. After two years under *zaï*, an initially barren field was found to be growing 23 herbaceous species and 13 species of trees and shrubs (Roose, Kaboré, abd Guenat 1995).

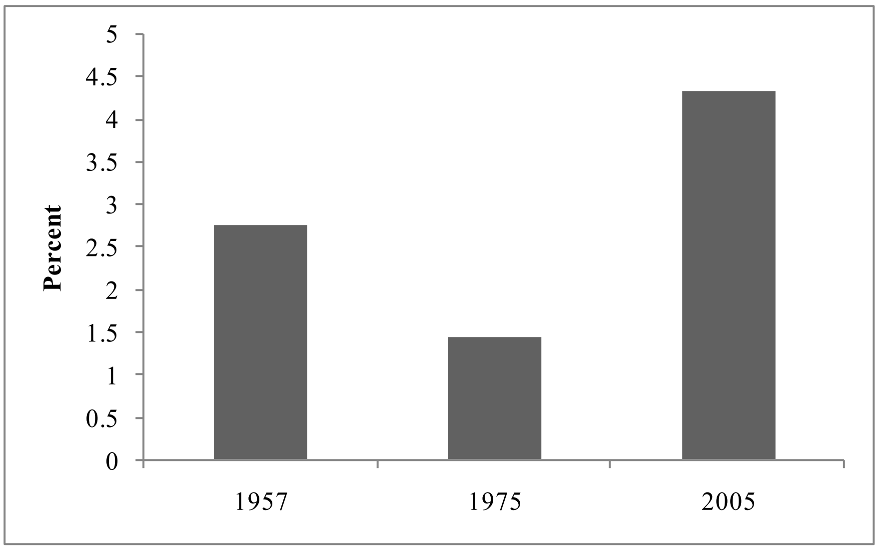
A survey in 58 villages in 2002, in which men and women were asked about the fluctuations in the level of water in their wells, revealed that in several regions, including the Yatenga and Zondoma provinces, the level of water in wells had improved significantly since the beginning of land rehabilitation (Reij and Thiombiano 2003).[12] As a result, farmers had created small vegetable gardens around several wells.

Were higher water levels in wells caused by groundwater recharge due to land rehabilitation or by increased rainfall since the mid-1990s? There is some reason to believe that this phenomenon is mainly related to land rehabilitation. First, water levels have only improved in those wells that are situated within rehabilitated areas or immediately downslope of these areas and not in wells situated upslope of rehabilitated areas. Second, rising water levels in some villages began during the dry period before the mid-1990s. In the villages of Rissiam and of Ranawa, for instance, the water situation was extremely precarious until land rehabilitation began in 1981/82 and 1984/85, respectively. Within two years, water levels rose. Whereas before rehabilitation all wells fell dry at the end of the rainy season, wells soon had water throughout the year. However, more research is required to establish the scientific relationship between land rehabilitation and groundwater recharge.

[12] The increase in water levels in wells is estimated to be about 5 meters (m). The reaction of a professor of hydrology at the University of Ouagadougou was "I measured the increase in the well in my village in the Yatenga; it was not 5 m, but 17 m."

Figure 9 presents a graph showing the average tree cover calculated from sampled frames of the Mirriah-Magaria-Matameye (MMM) study area of Niger. The V-shaped trend shows the significance of the parkland as it existed in 1957, followed by a loss of nearly half the tree cover by 1975, and more than three times the cover in 2005. In 1975, the parkland had not disappeared. Among the frames sampled, tree cover in 2005 ranged from less than 1 percent to nearly 8 percent. However, at more local scales, concentrations of trees of up to 16 percent cover were apparent. With the high density of young trees, the percent cover is expected to increase significantly over the next 10 years. This indicates the potential of this agroecological system to reach much higher levels than its current level. This has major implications for accruing biomass (and therefore carbon). FMNR has already sequestered important quantities of biomass, but there appears to be considerable potential for much more.

Figure 9. Average tree cover trends in the Mirriah-Magaria-Matameye (MMM) triangle (%)



Note: The graph shows the tree cover trends for 1957, 1975, and 2005 averaged over the 10 by 52 kilometer study area within the MMM triangle, Niger.

Source: Authors.

Agricultural Intensification, Diversification, and Population Dynamics

It is often assumed that increases in agricultural production in the Sahel are achieved by bringing more land under cultivation. Reij and Thiombiano (2003) have analyzed agricultural statistics for the northern part of the Central Plateau for the period of 1984–2001. The statistics indicate, with one exception, long-term stability of the area under cereals. The only exception is the area under sorghum in the Yatenga Province, which has increased by almost 30,000 ha since 1984. This extension has been made possible by land rehabilitation (Sawadogo 2008). The fact that sorghum is an important crop on rehabilitated land indicates the efforts of farmers to manage the fertility of these soils.

The complexity of production systems also appears to have rebounded. Although millet and sorghum remain the dominant crops in Burkina Faso, cowpea and sesame grown in small pure stands are increasing. Cotton was an important crop in the 1950s and even in the 1960s, but it disappeared from the Yatenga and Zondoma provinces in the 1970s, while continuing to be cultivated in relatively fertile valleys of the Bam Province. Farmers have begun re-introducing small plots of cotton on rehabilitated degraded land. More on-farm trees and more livestock, which is managed more intensively (Sawadogo 2003), also contribute to diversity. More vegetable cultivation adds to income and to more balanced nutrition.

Intensification and diversification has altered demographic dynamics in Burkina Faso. In the second half of the 1970s and the first half of the 1980s, many farm families abandoned their villages permanently and settled in the valleys in the south of Burkina Faso, which were freed from the small fly causing river blindness (McMillan 1988). It is common for men to migrate to urban areas after the harvest, where they are likely to earn higher wages. However, some indicators suggest that these patterns have changed. Census data for 1975, 1985, and 1996 from 14 study villages in the northern part of the Central Plateau (nine with longer and shorter histories of investment in land rehabilitation and three villages without such investments), show stable populations between 1975 and 1985 (16,224 inhabitants in 1975 and 16,543 in 1985). From 1985 to 1996, however, the population of the 14 villages grew by 25 percent (from 16,543 inhabitants in 1985 to 20,479 in 1996). With the exception of one village, the highest growth rates occurred in villages that had invested in land rehabilitation. The village of Ranawa (Zondoma Province) lost 25 percent of its population between 1975 and 1985, but its population doubled between 1985 and 1996. Since the land rehabilitation activities began in 1984/85, not a single family has left the village (Reij and Thiombiano2003). Again, further study is required to establish the extent to which reduced migration can be attributed to land rehabilitation.

Time-series, high-quality aerial photos of landscapes in south-central Niger clearly reveal a phenomenon of "more people, more trees." Figure 10 shows a time sequence of imagery over a landscape in the MMM study area south of Zinder, representing the years 1957, 1975, and 2005. The 1957 aerial photographs open a window into the landscapes of the past. Taken at the end of the colonial period during a relatively wet period, the region was, like today, devoted to rainfed agricultural production of cereal grains and peanuts. But unlike today, the rural population was perhaps a third of its current level. The aerial views attest to the use of the traditional bush fallow rotation system, an indication of land abundance, with 30 to 50 percent of the land typically remaining in grassy fallow (medium gray surfaces). Fallow periods were apparently fairly short, perhaps 1 to 3 years, judging from the lack of dense bush growth. Farmers maintained cattle corridors using live hedges to channel livestock from village to pasture, keeping them out of the crops during the growing season. Village sizes were much smaller and there were fewer of them. Natural depressions forming wetlands were much more pronounced, compared with today, owing to the contrast between aquatic and tall herbaceous vegetation and the farmed uplands. Trees were scattered throughout this ecosystem, locally concentrated in some areas and sparsely scattered in others.

The 1975 aerial photographs provide a stark contrast to the situation of the 1950s. Niger was just recovering from what may have been the twentieth century's worst drought (1968–73). The government, along with international donors and NGOs, was gearing up to improve food security. Numerous poorly designed and ill-fated projects were designed to combat desertification through tree plantations, windbreaks, and village woodlots (Rinaudo 2001).[13] The aerial views generally confirm the crisis. Much of the tree cover seen in the 1950s was gone—likely from the combined forces of human and livestock pressure on trees when crops and forage failed, from increased clearing for farming, and from drought-related tree mortality. While not absent, the use of fallow declined significantly, dropping to a typical range of 0 to 20 percent of the land area. Rural populations had roughly doubled since 1957, as seen in the sizes of villages. On a positive note, the natural wetlands (the dark patches in the aerial photography) appear relatively intact, providing sources of standing water and fresh grass during the early dry season. Compared to the 1950s, the traditional agricultural parkland was considerably thinner.

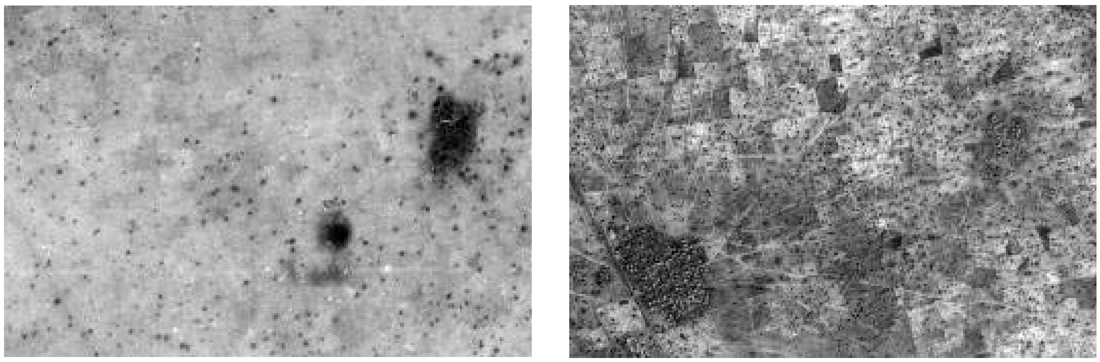
Looking at this imagery in 1975, no one could have predicted the extent of the renaissance of the parkland today. By 2005, the sparse tree cover of the 1970s was replaced by young and fast growing parkland. What is remarkable is not so much the increased tree cover—the croplands still receive ample sunlight—but there is a high density of trees, many of which are pruned to grow vertically, often in the inner fields around a village. Not surprisingly, village sizes have continued to swell. Numerous new settlements appear in the 2005 imagery. As human pressure on the landscape mounts, the use of fallow

[13] The windbreaks of the Maggia Valley (Niger) are a notable exception (Rochette 1989)

has all but disappeared. The natural wetlands have been converted to off-season gardens, oriented toward market sales.

Figure 11 shows another landscape in the MMM study area in the same sequence. Similarly, natural wetlands (two dark areas in the 1957 and 1975 photos) have been converted to off-season farmland. The time-series shows the large number of small trees that now reconstitute the young parkland.

Figure 10. Landscapes in the MMM study area (south of Zinder) in 1957, 1975, and 2005



Notes: Readiing (left to right), note the extensive grassy fallow land in 1957 (medium gray surfaces). The dark patch near the center is a wetland, converted to farmland by 2005. Note the large, new settlement that appears only in the 2005 image.

Figure 11. Another landscape in the MMM study area in 1957, 1975, and 2005

Note the natural wetlands (two dark areas in 1957 and 1975) that have been converted to off-season farmland, the decline in grassy fallow (medium gray areas in 1957 and 1975), six very small settlements in the 2005 image, and the large number of small trees that reconstitute the young parkland in 2005.

In their definitive study on evolving farming practices in eastern Burkina Faso, Mazzucato and Niemeijer (2000) found evidence of a form of agricultural intensification that allows food production to grow along with population. Similar findings are reported in research undertaken by Tappan and McGahuey (2007) in the Office de la Haute Vallée du Fleuve Niger (OHVN) of Mali, Mortimore et al. (2001) in the Maradi Department of Niger, and Faye et al. (2001) in the Diourbel Region of Senegal. Each of these studies demonstrates that in spite of population growth, agriculture has intensified and the environment has improved, with positive consequences for the local economy (Mortimore and Turner 2005).

Limitations

The major disadvantage of planting pits is that they are labor-intensive. Farmers must have access to family or hired labor to dig them, to dig compost pits, and to fill and maintain pits from year to year. So far, mechanization has not been feasible. The labor investments of *zaï* and contour stone bunds are high and even more so if both techniques are combined, which is what farmers in the Yatenga and Zondoma provinces frequently do. Estimates of total labor costs for planting pits vary with farmers' practices. Roose, Kaboré, and Guenat (1995) estimated 300 hours per ha, and Maatman (1999) estimated 450 to 650 hours depending on soil conditions. Although planting pits are simple and easy to dig, the high labor requirements for digging and managing them mean that relatively rich farmers can more easily hire labor to rehabilitate degraded land than poor farmers who have to rely on their own labor. Practice shows that richer farmers hire labor to rehabilitate land, which is likely to contribute to growing inequality. Small farmers can only incrementally rehabilitate degraded land to which they have access.

How much more extensive could adoption of these practices be? According to Roose,Kaboré, and Guenat (1993), zaï function best in areas with a minimum of 300 and a maximum of 800 mm of rainfall. With less than 300 mm the risk of crop failure becomes too big, and with more than 800 mm, the risk of the crop getting too much water increases. The soil surface should be barren, flat, and hard to generate sufficient runoff. Because they are labor-intensive, a relatively high population density facilitates their diffusion. A systematic study has not yet been undertaken in Burkina Faso to determine the area that can potentially be treated with water-harvesting techniques such as contour stone bunds, zaï, and half moons, but it is not less than hundreds of thousands of hectares.

There do not appear to be any negative offsite impacts of land rehabilitation, such as decreased water availability downstream. In social and economic terms, there are many winners, including women who have benefited from local groundwater recharge, more on-farm trees, and the rehabilitation of some of their plots. But are there any losers? One might argue that the Fulani herders are relative losers because the number of cattle entrusted to them by the Mossi farmers appears to have decreased. Mossi farmers now prefer to keep cattle close to their compounds to benefit more from livestock manure. This may have led to a loss of income by Fulani herders. On the other hand, herders can now sell manure for cash to Mossi farmers.

Potentially negative impacts of FMNR include an increase in pests, such as birds that cause damage to crops, competition between trees and crops for nutrients and sunlight, and a negative impact of higher tree densities on local groundwater tables. Larwanou and Adam (2008) have found one village that did not engage in FMNR because villagers were afraid of increasing pests. No other negative impacts have been observed during field work or documented in the literature. Farmers are aware of competition between trees and crops for nutrients, water, and sunlight. For example, in the village of Dan Saga (Maradi Region), on-farm tree densities have increased considerably, and in 2007 villagers began cutting on-farm trees to reduce densities and generate income from firewood.

7. SUSTAINABILITY

Quoting an ICRISAT study, Matlon (1985) reported that economic analysis of a package tested by ICRISAT (bunding in combination with a low dose compound fertilizer and an improved sorghum cultivar) showed that a break-even annual sorghum yield increment of only 155 kg would assure a return of 15 percent on the labor and cash investment. This increment was exceeded by 67 percent of farmers in the Sudano-Sahelian zone (which includes the northern part of the Central Plateau).

Kaboré and Reij (2004) estimate the gross margins of *zaï* per hectare of about $184 and returns to labor of $0.19 per hour and $1.14 per six-hour day. This wage is about 33 percent higher than farmers' estimates of dry-season wages. The authors only take into account the impacts on crop production and stover.

Soil and water conservation projects have calculated the costs of rehabilitating 1 ha of degraded land. The cost estimates vary from project to project, but costs are on the order of $200/ha. This means that the equivalent of at least $40 million has been invested in land rehabilitation on the Central Plateau. The estimated additional cereal production (at least 80,000 tons) is enough to cover the annual cereal needs of about 400,000 people. The monetary value of this additional cereal production is on the order of $19.2 million /year.[14]

Existing estimates of internal rates of return to project investments refute the popular perception that because dryland environments are difficult and market infrastructure is often also poor, investing in them "doesn't pay." A project in Illela District, Niger, benefited from unusually thorough monitoring during the project and from subsequent surveys (Hassane, Martin, and Reij 2000). Total project cost during 1988–95 was $1.5 million, with an estimated economic rate of return at completion of 20 percent (Reij and Steeds 2003).

Using ICRISAT cost data and lower yield differentials estimated for researcher-managed fields, Wright (1985) and Younger and Boukoungou (1984) estimated an internal rate of return to the PAF project of about 40 percent. For an additional hectare of barren land reclaimed, the rate of return they calculated was 147 percent. These calculations did not capture the effects of bund construction by one farmer on other farmers' fields or the possible cost-reducing effects of construction by a group, compared with construction by an individual.

Abdoulaye and Ibro (2006) calculated an internal rate of return of 31 percent for FMNR. Their calculation was based on the value of firewood produced during a period of 20 years and an increase in cereal yields of 5 percent during the first five years. Although 31 percent is attractive from an economic point of view, the authors seriously underestimated the benefits of FMNR because they did not attempt to value other impacts of FMNR.

A major shortcoming in economic evaluations of *zaï* or contour stone bunds is that the wrong counterfactual is chosen. Usually a comparison is made between yields obtained on rehabilitated fields and average yields on cultivated fields. To most farmers, the real counterfactual is 0 kg/ha and every single kilo harvested is a net gain. From the perspective of the individual farmer, benefits expressed in single-year yield advantages, or partial budgets, are understated because they do not incorporate a decreased risk of crop failure or positive, longer-term impacts on trees, tree products, other vegetation, and water on the farm. From the viewpoint of the community, they omit off-site effects of increased biomass, groundwater recharging, and stimulation of local markets. From the viewpoint of the society as a whole, they exclude the benefits of reducing migration, mitigating climate change, and combating environmental degradation. Similarly, impacts of project investments are underestimated. With respect to internal rate of return to project investment, impacts continue after project completion. At the same time, given the number of contributing projects, impacts would be more appropriately analyzed at a larger scale.

[14] This calculation is based on an average cereal price of CFA 12,000/100 kg, or $240 per ton.

No study has systematically quantified the impacts of FMNR, but Larwanou and Adam (2008) have made a useful first step in this direction. If the number of trees has increased by 40 trees/ha (trees of all ages) on a scale of 5 million ha, then FMNR has added about 200 million new trees to Niger's tree stock.[15] Trees affect local climate, crop growth and yields, soil fertility, and the availability of fodder, fruit, and other nontimber forest products. Larwanou and Adam (2008) assume that every tree produces an average value of $1.40 per year in the form of improved soil fertility, fodder, fruit, firewood, and other produce. This would mean an additional value of at least $56/ha/year[16] and a total annual production value of $280 million.

Little conforms to a business model of development in this story of farmers who combated the degradation of their lands and daily lives with arduous labor against tremendous odds. At the same time, there are numerous examples of how undertaking these environmental changes instigated other changes, enabling farmers to create small businesses. There are also examples of farmers who provided public goods (training, rehabilitation, demonstration) at private cost because they benefited from greater social standing.

The longevity of this innovation process (two to three decades) attests to its social and political sustainability. In fact, "…the *processes* described here for involving farmers in technology development and testing may well prove more readily transferable than the individual technologies themselves" (Haggblade and Hazell 2009).

Despite these advances, "the battle against land degradation and rural poverty on the Central Plateau has not yet been won" (Reij, Tappan, and Belemvire 2005). Nor has it been won elsewhere in the Sahel. FMNR alone will not enable Niger or other Sahelian countries to keep abreast of the needs of a burgeoning population—but it is one important tool.

Finally, a remark should be made about the demographic context in the Sahel. Population growth in densely populated regions has induced a process of agricultural intensification, but current demographic growth rates will lead to a doubling of the population in 20 years or less. Niger now has about 15 million people and in 2030 it will have about 30 million. No government can be expected to cope with such growth rates. In 1984, no one believed that Niger would be where it is in 2009, but will it be able to pull off a similar surprise in 2030?

[15] Average tree densities measured in villages in the Maradi and Zinder regions by Saadou and Larwanou (2005) and by Larwanou and Adam (2008) were well above 40 trees/ha.

[16] This is most likely an underestimation. The Eden Foundation, which operates in the Tanout, a drier region north of Zinder, calculates that in 2007 farm households harvested fruit, leaves, and berries worth an average of 74 euros ($103) per household.

8. LESSONS FOR POLICY AND PRACTICE

Much has been invested by farmers, government, and donor agencies in land rehabilitation on the Central Plateau of Burkina Faso. Much has been achieved, but the battle against land degradation and poverty has not yet been won. As shown here, these investments have generated various positive impacts since 1980. Despite this fact, most donor agencies, with the exception of the International Fund for Agricultural Development (IFAD), have ceased or reduced funding for land rehabilitation. Land rehabilitation enables sustainable intensification of agriculture and more resilient food production systems. Findings indicate that it contributes to maintaining socially and economically viable rural communities, stemming the tide of migration to overpopulated urban areas; curbing incentives for farmers in the Central Plateau to resettle in other, more favorable areas; and reducing tensions among population groups competing for scarce resources.

This is not a call for keeping people on the Central Plateau in poverty but a call to view continued investments in soil, water, and agroforestry as essential to intensifying agriculture, securing livelihoods in this region, and mitigating global climate change. Much has been achieved in terms of improving agriculture and environment since René Dumont, a former French presidential candidate, produced a report about Burkina Faso in 1984 titled "*Burkina Faso n'est pas un pays en voie de développement, mais un pays en voie de disparition*" ("Burkina Faso is not a developing country, but a country in the process of disappearing"). Yet much land remains to be rehabilitated and on other cultivated land, agroforestry systems and soil fertility management can be improved.

Similarly, in 1984, it seemed as if Niger would be blown from the map. Drought and strong winds from the desert (*harmattan)* created a general feeling of despair. No one could have imagined that farmers in densely populated parts of Niger would significantly increase on-farm tree densities with minimal external support and that the scale at which they would do it would not be publicly recognized for many years. Ironically, this may have occurred precisely because donors did not place their signboards on it. The agroenvironmental transformation depicted here may have been "invisible" to governments and donors because it was derived from the grassroots, needing little input from outsiders.

Farmer-managed natural regeneration is not a solution to all problems, but it is low cost and produces multiple, long-term benefits. An added advantage is that FMNR is managed and maintained by land users. There are no recurrent costs to governments or donor agencies. Haggblade and Hazell (2009) argue that agricultural development approaches of this type are much cheaper than fertilizer subsidies. Reij, Tappan, and Belemvire (2005) point out that more than 100,000 ha treated with contour stone bunds cost an estimated $200/ha for labor, transport, and technical support, which was comparable to the cost of one major dam to improve the water supply of the capital city of Ouagadougou. In FMNR, as well as land rehabilitation, there is considerable scope for building on existing larger and smaller successes in Burkina Faso, Niger, and other Sahelian countries.

These stories carry five important lessons about effective partnerships for agricultural development. First, both "barefoot" science and cutting-edge science are important, particularly in environments such as these. The most successful innovations are often simple, low-cost improvements on practices that are locally available and already known to farmers. Second, a single technique or practice is in itself generally insufficient to achieve meaningful environmental and economic impacts but acts as a trigger for other innovations. When farmers undertook multiple innovations simultaneously they accomplished more rapid environmental change through the synergies of soil, water, and vegetative regeneration in a crop, tree, and livestock system. Diversification of economic opportunities along with these changes generated self-reinforcing feedback. Third, a single "menu" of technical options can be adopted on a large scale, but to be widely adopted, the menu must be flexible, adaptable, and testable by farmers under their own heterogeneous social, economic, and environmental conditions. Farmers can select the number and combination of practices that best meet their needs. Fourth, in resource conservation, adoption on single fields or farms allows individual farmers to achieve impacts, but collective action at the level of communities produces more sustainable benefits. Finally, farmers are much more likely to adopt resource conservation innovations if at least one innovation or component will provide significant benefits in the first or second year.

Organizational and institutional innovations, including the coordinated, flexible configurations of actors, were needed to attain widespread diffusion of the technical innovations. At the outset, the projects that claimed success tended to be fairly small in scale, involving local farmers closely in the design of technical solutions. In project design, flexibility to respond to farmer demands or to new opportunities proved to be a strength. Promoting local leadership has led to positive results. Charismatic leaders, both local and from outside the community, stimulated change through their own choices and actions and provided personal role models for others. In a number of the stories recounted, leaders were willing to take action in ways that were socially risky because they diverged from customary behavior. Tackling tough conservation problems needs strong village institutions and local leadership.

Multiple diffusion models should be envisaged because no single model works in all communities. In some cases, innovative practices were adopted by individuals on their farms, and in others, by groups working collectively across farms or on collective fields. Thus, some will be based on farmer-to-farmer training by individuals, while other approaches will use interactive, social learning in farmer groups. The poorest in poor communities will always be hard to reach. Special mechanisms may need to be established so they can benefit from innovations.

The stories recounted here have immediate, global implications: they are among the first examples of poor farmers' successes in enhancing food security while adapting to climate change. Much has been learned regarding the sustainability of such efforts. Investments in tree regeneration and in on-farm water harvesting techniques in semi-arid regions have led to immediate and perceptible yield increases and contributed to reducing rural poverty. Returns accrue already in the first or second year after the initial investment. The innovation process is sustainable when led by farmers. Long-term investment in building human and social capital enables rural communities to lead and manage. Land users in drylands respond to market opportunities, but intensification and commercialization do not necessarily cause overexploitation. Long-term investment in road and information infrastructure, which enhances the ability of farmers to diversify income from sales of tree, crop, and livestock products, can support the investments by farmers. Government support of farmer-led initiatives, public education and awareness about the agroenvironment, and legal frameworks with use rights for farmers have contributed to positive change. Macroeconomic policies, such as exchange rates and agricultural pricing policies, will have impacts on farmers' incentives to manage their crops, trees, and livestock more sustainably.

APPENDIX A. UNCOVERING THE GEOGRAPHIC EXTENT OF FARMER-MANAGED NATURAL REGENERATION

Field observations of the geographic extent of landscape transformation in Niger led immediately to the following questions: (1) Why didn't remote sensing scientists detect this transformation earlier with satellite imagery? (2) If this phenomenon is so significant, why did it fly under the radar for so long?

Earlier detection of FMNR across southern Niger eluded environmental experts for several reasons. First, the predominant literature concerning agriculture and the environment in the Sahel is replete with narratives about severe population pressure on limited, fragile resources, resulting in natural resource degradation. Southern Niger, with its very high rural population, was assumed to be highly degraded, with far less tree cover than it had before the drought of the 1970s. Many authors cite evidence of negative rainfall trends, causing soil erosion and loss of vegetation cover. The counternarratives—the body of literature devoted to environmental successes—were limited to local studies. Few thought to look for positive changes at a regional scale. By the mid-2000s, however, several papers were published using the U. S. National Aeronautic and Space Administration's (NASA's) long-term Normalized Difference Vegetation Index (NDVI), based on a long-term time-series archive of satellite imagery from the National Oceanic and Atmospheric Administration going back to 1982. These provided some indication of environmental improvements in the Sahel, including a recently observed greening trend (Eklundh and Olsson 2003; Olsson, Eklundh, and Ardö 2005; Herrmann, Anyamba, and Tucker 2005). The Maradi-Zinder corridor did show an increased greening trend, but it did not stand out above many other areas in the Sahel that also showed a similar trend. The results did not single out this region.

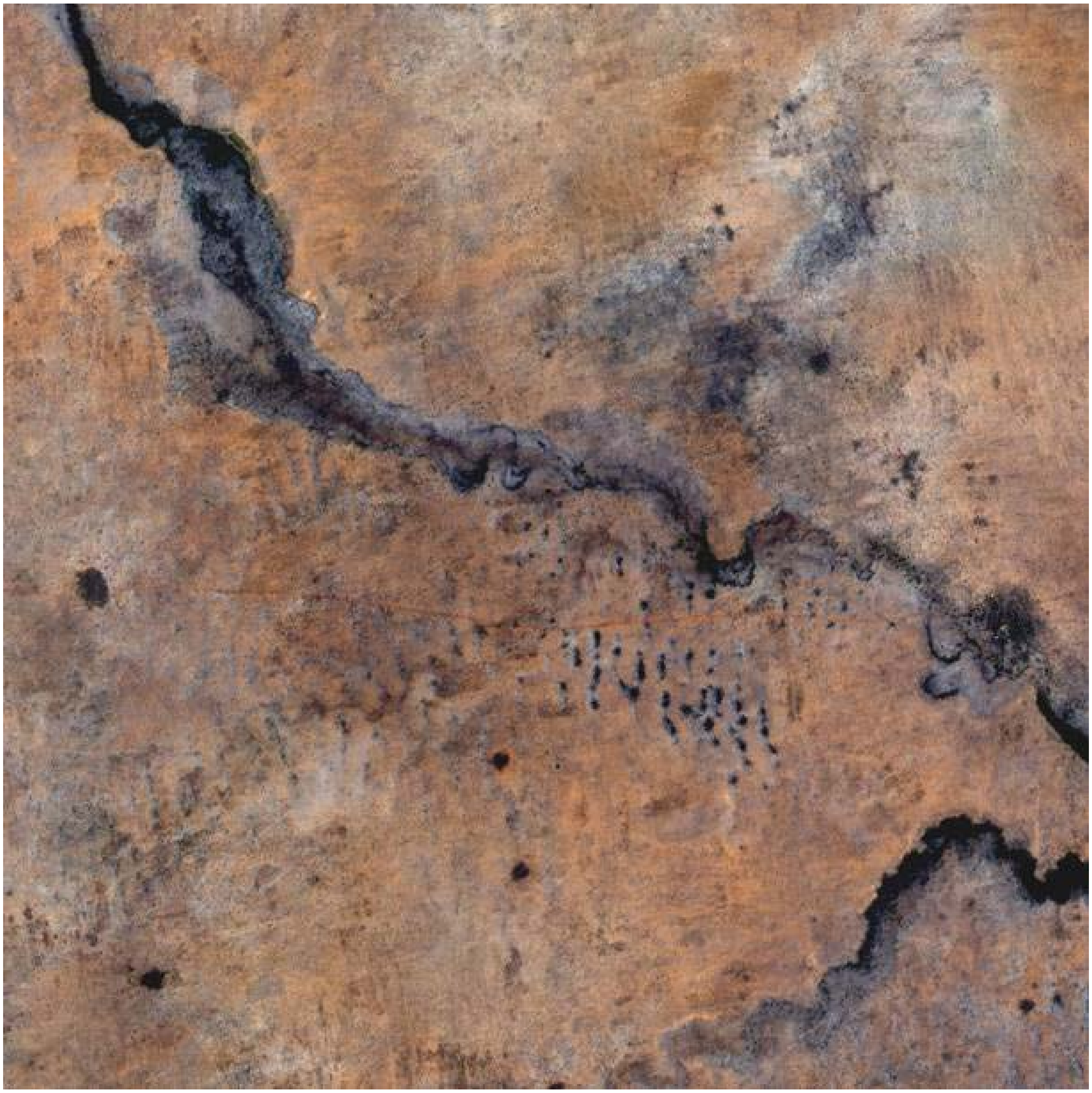
Remote sensing scientists at the U.S. Geological Survey/EROS Center had been working with medium resolution Landsat imagery in a collaborative effort with the AGRHYMET Regional Center and Niger's *Direction de l'Environnement* to map the land use and land cover of Niger from 1975 to 2000. Their work culminated in land use/land cover maps of the country, showing among other trends the expansion of agricultural area in the Maradi and Zinder Regions. However, change in within-class land cover was not one of the characteristics they mapped.

Perhaps the most significant reason that remote sensing scientists missed the nascent regreening of the region's agricultural landscapes was the fact that medium-resolution satellite imagery, predominantly from the Landsat satellites (30-meter resolution), does not provide enough detail to see the trees. Additionally, the predominant species, the winter thorn or *gao* tree (*Faidherbia albida*), is unique in that it sheds its leaves at the onset of rains. Even in the dry season, the *gao* tree presents a rather sparse canopy to the aerial observer or remote sensor (Figure 12). Even the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery, with twice the detail of Landsat, fails to turn up the emerging sea of on-farm trees (Figure 13).

Figure 12. An aerial view of a parkland dominated by *gao* trees, Niger

Notes: The trees are in a leaf-off stage during the rainy season and do not contribute to the greenness of the landscape. Their presence can go undetected in satellite image analyses using vegetation indexes.

Figure 13. Enlarged portion of an ASTER image, Niger



Notes: This image was acquired in February 2007 over some of the denser tree parkland areas of FMNR within Niger's Mirria-Magaria-Matameye (MMM) triangle. Even at 15-meter resolution, the relatively dense tree cover is not readily detected on the sandy uplands that dominate this scene. This area is centered about 15 km east of Matameye. The small linearly aligned dark features are humid interdune depressions that support wetlands and off-season crops. The image depicts an area about 12 km wide.

APPENDIX B. SOURCES AND METHODS OF REMOTE SENSING

The remote-sensing approach consisted of (1) obtaining complete coverage of recent high-resolution satellite imagery across the Maradi-Zinder agricultural region to confirm the density and distribution of FMNR and (2) obtaining high-resolution imagery for three time periods of a more targeted area where we knew FMNR was widely practiced. The focus area was a rectangular swath within the MMM triangle in the Zinder Region (see Figure 14 for focus area location). This study area represents a typical slice of the MMM triangle as determined by examination of recent high resolution imagery over the greater area.

Figure 14. Location of the remote sensing focus area (black rectangle) within the agricultural plains of southern Niger.

Note: The three dots indicated by the black dash show the locations of Mirriah, Magaria, and Matameye, which define a triangle of relatively dense FMNR.

For the Maradi-Zinder agricultural region, a combination of WorldView 1 high-resolution digital panchromatic satellite imagery (0.5-meter resolution) and QuickBird (2.8-meter resolution) multispectral satellite imagery was obtained, covering the entire region. The WorldView images were acquired between 2006 and 2008, while the QuickBird imagery ranged from 2003 to 2008. Nearly all of the imagery was acquired during the dry season, which facilitated tree inventories. In the dry season, there is increased contrast between tree canopy and background soil reflectance. In addition, the often dominant *gao* trees are in their leaf-on stage, presenting a dark canopy in the visible spectral bands. Figure 15 shows an example of a QuickBird satellite image over a typical medium-density tree parkland.

To assess the extent and relative density of tree cover (and FMNR), we systematically sampled the entire agricultural region (including adjacent areas of Nigeria) by assessing tree cover at 1 X 1 km sites at 10-minute intervals of latitude and longitude. A total of 378 sites distributed in a grid pattern were examined using the high-resolution imagery. Trees were visually identified using a standard photo-interpretation approach. Tree densities were ranked into five classes, ranging from “no tree cover” to “high-density tree parkland.” The first two classes (no tree cover and open with isolated trees) are landscapes without FMNR. FMNR was considered to be present in the low-, medium-, and high-density tree parkland classes. A map was prepared to visually characterize the patterns and extent of tree cover, using colored square symbols to represent the classes of tree cover at each 1 X 1 km site (shown earlier in Figure 6). The square symbols are not to scale; that is, the sample sites were too small to represent at the scale of the map. Finally, to determine the area of FMNR, we tallied the number of sites with tree parklands. The proportion of tree parkland sites relative to the total number of sites established provided the figure of 4,828,500 ha for this region.

Figure 15. Example of a portion of a QuickBird satellite image

Notes: The image shows medium-density tree parkland in cropland 30 km west of Maradi. Note the cattle corridors connecting villages to remote grazing lands. This image represents an area 1.8 km wide; it was acquired on October 15, 2005.

For the MMM zone, we acquired time-series imagery over a 10 by 52 km swath. This consisted of aerial photography from 1957 (taken by the Institut Géographique National of France), aerial photography from 1975, and QuickBird high-resolution multispectral imagery from 2005. The imagery depicts landscapes during the dry season. In all cases, trees with canopies as small as 4 m in diameter are visible.

Next, the percentage of tree cover was measured for the same locations for the three time periods. This involved systematically sampling the 10 by 52 km study area by locating a 500 X 500 m image framed at 5-km intervals along lines of longitude and at 3-km intervals along lines of latitude. Thirty sample frames were used. Using a GIS (Geographic Information System), the three dates of imagery were coregistered using permanent landscape features, and the sample frames were extracted for analysis. The percentage of tree cover was quantified for each frame of imagery using a fine dot grid overlaid randomly. Dots "touching" a tree canopy were counted, and the proportion of dots was compared to the total number of dots to derive the percentage of tree cover for each frame. The time-series frames were also analyzed to look for other trends in the landscapes over the 48-year period.

Analysis of the 30 frames of imagery for the periods of 1957, 1975, and 2005 within the 10 X 52 km study area allowed the quantification of the percent of tree cover. The tree cover results from the 30 frames for each period were averaged to provide an estimate of overall tree cover for the study area. Results are shown in the graph in Figure 9.

In 2007 and 2008, the team returned to the field to conduct measurements of tree cover, woody biomass, and biodiversity in the MMM region. These measurements were carried out on 1-ha ground plots at 13 sites within the MMM zone. The sites were not selected randomly, but on a wide range of tree densities to establish a relationship between tree cover and woody biomass. Some sites were deliberately selected in areas of relatively high tree concentrations because these represent the actual potential of the ecosystem to sustain high numbers of trees on cropland. At each plot, tree diameters were measured (at breast height), along with tree heights and canopy diameter by species. Using an allometric equation developed for tropical drylands as recommended by Brown (1989), the estimated dry woody biomass was computed for each tree using the tree measurements. The biomass totals for all trees were summed for each 1-ha plot. These biomass measurements and their strong positive correlation with tree cover measured from the imagery will be used to estimate woody biomass and its trend over time in the study area and, eventually, across other parts of this agricultural region. Results from this analysis will be published separately.

REFERENCES

Abdoulaye, T., and G. Ibro. 2006. *Analyse des impacts socio-économiques des investissements dans la gestion des ressources naturelles: Etude de cas dans les Régions de Maradi, Tahoua et Tillabéry (Niger).* Niamey: Centre Régional d'Enseignement Spécialisé en Agriculture, Université Abdou Moumouni.

Adam, T., T. Abdoulaye, M. Larwanou, B. Yamba, C. Reij, and G.Tappan. 2006. Plus de gens, plus d'arbres: La transformation des systèmes de production au Niger et les impacts des investissements dans la gestion des ressources naturelles. Rapport de Synthèse Etude Sahel Niger. Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel and Université de Niamey, Niamey.

Anyamba, A., and C. J. Tucker. 2005. Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. *Journal of Arid Environments* 63: 596–614.

Atampugre, N. 1993. *Behind the lines of stone: The social impact of a soil and water conservation project in the Sahel*. Oxford, U.K.: Oxfam Publications Unit.

Aubréville, A. 1949. *Climats, forêts, et désertification de l'Afrique tropical*. Paris: Société d'Editions Géographiques, Maritimes, et Coloniales.

Awaïss, A. 2000. Gestion des forêts et des arbres au niveau des terroirs dans la Région de Maradi. Drylands Research Working Paper 31. Crewkerne, U.K.: Drylands Research.

Baoua, I. 2006. *Analyse des impacts des investissements dans la gestion des ressources naturelles sur le secteur élevage dans les régions de Maradi, Tahoua et Tillabéry au Niger*. Niamey: Centre Régional d'Enseignement Spécialisé en Agriculture, Université de Niamey.

Belemvire, A. 2003. Impact de la conservation de l'eau et des sols sur la régénération naturelle assistée. *Développement rural et environnement au Burkina Faso: La réhabilitation de la capacité des terroirs sur la partie Nord du Plateau central entre 1980 et 2000.* Rapport de travail no. 1. .Ouagadougou, Burkina Faso: Conseil National pour la Gestion de l'Environnement

Belemviré, A., A. Maïga, H. Sawadogo, M. Savadogo, and S. Ouedraogo. 2008. *Evaluation des impacts biophysiques et socio-économiques des investissements dans les actions de gestion des ressources naturelles au Nord du Plateau Central du Burkina Faso.* Rapport de Synthèse Etude Sahel Burkina Faso. Ouagadougou, Burkina Faso: Comité Inter-Etats pour la Lutte contre la Sécheresse au Sahel.

Boffa, J-M. 1999. Agroforestry parklands in Sub-Saharan Africa. *FAO Conservation Guide* 34. Rome: FAO.

Botoni, E., and C. Reij. 2009. *La transformation silencieuse de l'environnement et des systèmes de production au Sahel: L'impacts des investissements publics et privés dans la gestion des ressources naturelles.* Amsterdam, the Netherlands: Comité Permanent Inter-Etats de Lutte Contre la Secheresse dans le Sahel (CILSS) and Vrije University Amsterdam.

Broekhuyse, J. Th. 1983. Transformatie van Mossi land. Amsterdam, the Netherlands: Koninklijk Instituut voor de Tropen.

Brown, S., A. J. R. Gillespie, and A. E. Lugo. 1989. Biomass estimation methods for tropical forests with application to forest inventory data. *Forest Science* 35: 881–902.

Critchley, W. 1991. *Looking after our land: Soil and water conservation in dryland Africa*. Oxford, U.K.: Oxfam.

de Graaff, J. 1996. The price of soil erosion: An economic evaluation of soil conservation and watershed development. PhD dissertation, Wageningen University, Wageningen, the Netherlands.

Dugue, P. 1989. *Possibilités et limites de l'intensification des systèmes de culture vivriers en zone soudano-sahélienne: Le cas du Yatenga (Burkina Faso).* Collection Documents Systèmes Agraires No. 9. Montpellier, France: Centre de Coopération International en Recherche Agronomique pour le Dveloppement (CIRAD).

Eklundh, L., and L. Olsson. 2003. Vegetation index trends for the African Sahel 1982–1999. *Geophysical Research Letters* 30: 13-1–13-4.

Faye, A., A. Fall, M. Tiffen, M. Mortimore, and J. Nelson. 2001. Région de Diourbel (Sénégal): Synthesis. Drylands Research Working Paper No. 23. Crewkerne, U.K.: Drylands Research.

Haggblade, S., and P. Hazell, eds. 2009. *Successes in African agriculture: Lessons for the future*. Baltimore, Md., U.S.A.: Johns Hopkins University Press, forthcoming.

Harrison, P. B. 1987. *The greening of Africa: Breaking through in the battle for land and food.* London: Paladin Grafton Books.

Hassane, A., P. Martin, and C. Reij. 2000. *Water harvesting, land rehabilitation, and household food security in Niger: IFAD's soil and water conservation project in Illela District*. Amsterdam, the Netherlands: International Fund for Agricultural Development (IFAD)/VU University Amsterdam.

Herrmann, S. M., A. Anyamba, and C. J. Tucker. 2005. Recent trends in vegetation dynamics in the Africa Sahel and their relationship to climate. *Global Environmental Change* 15: 394–404.

Hien, F., and A. Ouedraogo. 2001. Joint analysis of the sustainability of a local SWC technique in Burkina Faso. In *Farmer innovation in Africa: A source of inspiration for agricultural development,* ed. C. Reij and A. Waters-Bayer. London: Earthscan.

Joet, A., P. Jouve, and M. Banoin. 1998. Le défrichement amélioré au Sahel: Une pratique agoforestière adoptée par les paysans. *Bois et Forêts des Tropiques* 255: 31–44.

Kaboré, P. D., and C. Reij. 2004. *The emergence and spreading of an improved traditional soil and water conservation practice in Burkina Faso*. Environment and Production Technology Division Discussion Paper 114. Washington, D.C.: International Food Policy Research Institute.

Kaboré, V. 1995. *Amélioration de la production végétale des sols dégradés (zipellés) du Burkina Faso par la technique des poquets (zaï)*. PhD dissertation, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.

Kambou, N. F. 1996. *Contribution à la restauration et à la réhabilitation des sols ferrugineux superficiellement encroûtés (Zipella) du Plateau Central du Burkina Faso (Cas de Yilou-Province du Bam).* PhD dissertation, Université de Cocody, Côte d'Ivoire.

Larwanou, M., and T. Adam. 2008. Impacts de la régénération naturelle assistée au Niger: Etude de quelques cas dans les Régions de Maradi et Zinder. Synthèse de 11 mémoires d'étudiants de 3ème cycle de l'Université Abdou Moumouni de Niamey, Niger. Photocopy.

Larwanou, M., M. Abdoulaye, and C. Reij. 2006. *Etude de la régénération naturelle assistée dans la Région de Zinder (Niger): Une première exploration d'un phénomène spectaculaire*. Washington, D.C.: International Resources Group for the U.S. Agency for International Development.

Luxereau, A., and B. Roussel. 1997. *Changements écologiques et sociaux au Niger: Des interactions étroites*. Paris: L'Harmattan.

Maatman, A. 1999. *Si le fleuve se tord, que le crocodile se torde: Une analyse des systèmes agraires de la région nord-ouest du Burkina Faso à l'aide des modèles de programmation mathématique*. Groningen, the Netherlands: University of Groningen, Centre for Development Studies.

Marchal, J. Y. 1977. Evolution des systèmes agraires: L'exemple du Yatenga (Haute Volta). *Environnement Africain* 2: 75–88.

________. 1979. L'espace des techniciens et celui des paysans: Histoire d'un périmètre anti-érosif en Haute-Volta. In *Maîtrise de l'espace agraire et développement en Afrique Tropicale: Logique paysanne et rationalité technique.* Mémoires *ORSTOM* no.89. Paris: ORSTOM,

________. 1985. La déroute d'un système vivrier au Burkina: Agriculture extensive et baisse de production. *Etudes Rurales* 99/100: 265–277.

Matlon, P. J. 1985. *Annual report of ICRISAT/Burkina Economics Program.* Ouagadougou, Burkina Faso: International Crops Research Institute for the Semi-arid Tropics.

________. 1990. Improving productivity in sorghum and pearl millet in semi-arid Africa. *Food Research Institute Studies* 22 (1): 1–43.

Matlon, P. J., and D. S. Spencer. 1984. Increasing food production in Sub-Saharan Africa: Environmental problems and inadequate technical solutions. *American Journal of Agricultural Economics* 66 (5): 672–676.

Mazzucato, V., and D. Niemeijer. 2000. *Rethinking soil and water conservation in a changing society: A case study in eastern Burkina Faso.* Tropical Resource Management Papers 32. Wageningen, the Netherlands: Wageningen University.

McMillan, D. E. 1988. The social impacts of planned settlement in Burkina Faso. In *Drought and hunger in Africa: Denying famine a future,* ed. M. H. Glantz. Cambridge, U.K.: Cambridge University Press.

Monimart, M. 1989. *Femmes du Sahel: La désertification au quotidien*. Paris: Editions Karthala/Organisation for Economic Cooperation and Development Club du Sahel.

Mortimore, M., and B. Turner. 2005. Does the Sahelian smallholders' management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification? *Journal of Arid Environments* 63: 567–595.

Mortimore, M., M. Tiffen, Y. Boubacar, and J. Nelson. 2001. *Synthesis of long-term change in Maradi Department 1960–2000*. Drylands Research Working Paper 39. Crewkerne, U.K.: Drylands Research.

Olsson, L., L. Eklundh, and J. Ardö. 2005. A recent greening of the Sahel—Trends, patterns and potential causes. *Journal of Arid Environments* 63: 556–566.

Ouedraogo, A., and H. Sawadogo. 2001. Three models of extension by farmer innovators in Burkina Faso. In *Farmer innovation in Africa: A source of inspiration for agricultural development,* ed. C. Reij and A. Wayers-Bayer. London: Earthscan.

Ouedraogo, B. L. 1990. *Entraide villageoise et développement: Groupements paysans au Burkina Faso*. Paris: l'Harmattan.

Ouédraogo, S. 2005. *Intensification de l'agriculture dans le Plateau Central du Burkina Faso. Une analyse des possibilités à partir des nouvelles technologies*. PhD dissertation, Université de Groningen, the Netherlands.

Rands, B. 1996. Natural resources management in Niger: Lessons learned. Agriculture Sector Development Grant, phase II. Report submitted to U.S. Agency for International Development by the International Resources Group.

Raynaut, Cl. 1987. L'agriculture nigérienne et la crise du Sahel. *Politique africaine* 27: 97–107.

________, ed. 1997. *Sahels: diversité et dynamiques des relations sociétés-nature*. Paris: Editions Karthala.

________. 2002. *Réduction de la vulnérabilité et appui aux innovations paysannes: Perspectives pour une stratégie de développement local*. Rome: International Fund for Agricultural Development, Mission de Pré-évaluation.

Reardon, T., P. Matlon, and C. Delgado. 1988. Coping with household-level food insecurity in drought-affected areas of Burkina Faso. *World Development* 16 (9): 1065–1074.

Reij, C. 1983. L'évolution de la lutte anti-érosive en Haute Volta: Vers une plus grande participation de la population. Institute for Environmental Studies, Vrije University, Amsterdam, the Netherlands.

Reij, C., and E. M. A. Smaling. 2007. 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.

Reij, C., and D. Steeds. 2003. Success stories in Africa's drylands: Supporting advocates and answering skeptics. Paper commissioned by the Global Mechanism of the Convention to Combat Desertification. Vrije University and Centre for International Cooperation, Amsterdam, the Netherlands.

Reij, C., and T. Thiombiano. 2003. *Développement rural et environnement au Burkina Faso: La réhabilitation de la capacité productive des terroirs sur la partie nord du Plateau Central entre 1980 et 2001.* Ouagadougou, Burkina Faso: Ambassade des Pays-Bas, German Agency for Technical Cooperation-PATECORE, and U.S. Agency for International Development.

Reij, C., G. Tappan, and A. Belemvire. 2005. Changing land management practices and vegetation in the Central Plateau of Burkina Faso (1968–2002). *Journal of Arid Environments* 63 (3): 642–659.

Rinaudo, T. 2001. Utilizing the underground forest: Farmer-managed natural regeneration of trees. In *Combating desertification with plants*, ed. D. Pasternak and A. Schlissel. New York: Kluwer Academic/Plenum Publishers.

Rochette, R. M. 1989. Le Sahel en lutte contre la désertification: Leçons d'expérience. Josef Margraf Verlag, Weihersheim, Germany.

Roose, E., V. Kaboré, and C. Guenat. 1993. Le zaï: Fonctionnement, limites et amélioration d'une pratique traditionnelle de réhabilitation de la végétation et de la productivité des terres dégradées en région soudano-sahélienne (Burkina Faso). *Cahiers ORSTOM, Série Pédologie* 28 (2): 159–173.

________. 1995. Le zaï, une technique traditionelle africaine de réhabilitation des terres dégradées de la région soudano-sahélienne (Burkina Faso). In *L'homme peut-il refaire ce qu'il a défait?,* ed. R. Pontanier, A. M'Hiri, N. Akrimi, J. Aronson, and E. Le Floc'h. Paris: John Libbey Eurotext.

Saadou, M., and M. Larwanou. 2005. *Evaluation de la flore et de lavégétation dans certains sites traités et non-traités des Régions de Tahoua, Maradi et Tillabéri.* Niamey, Niger: Centre Régional d'Enseignement Spécialisé en Agriculture, Université de Niamey.

Sanders, J. H., and M. Roth. 1985. Développement et évaluation de nouveaux systèmes de production agricole: quelques résultats de terrain et résultats modèles obtenus au Burkina Faso pour les billons cloisonnés et la fertilisation. In*Technologies appropriées pour les paysans des zones semiarides de l'Afrique de l'Ouest,* ed. H. W. Ohm and J. G. Namy. West Lafayette, Ind., U.S.A.: Purdue University.

Sanders, J. H., J. G. Nagy, and S. Ramaswamy. 1990. Developing new agricultural technologies in Burkina Faso and the Sudan: Implications for future technology design. *Economic Development and Cultural Change* 39 (1): 1–22.

Savy, M., Y. Martin-Prevel, P. Traissac, S. Emyard-Duvernay, and F. Delpeuch. 2006. Dietary diversity scores and nutritional status of women change during the seasonal food shortage in rural Burkina Faso. *Journal of Nutrition* 136: 2625–2632.

Sawadogo, H. 2003. *Impact des aménagements sur les systèmes de production, les rendements et la sécurité alimentaire des exploitations agricoles*. Working Paper No. 2. Développement Rural et Environnement au Burkina Faso.

________. 2006. Fertilisation organique et phosphatée en système de culture zaï en milieu soudano-sahélien du Burkina Faso. PhD dissertation, Faculté Universitaire des Sciences Agronomiques de Gembloux, Gembloux, Belgique.

________. 2008. *Impact des aménagements de conservation des eaux et des sols sur les systèmes de production, les rendements et la fertilité au Nord du Plateau central du Burkina Faso.* Etude Sahel Burkina Faso. Amsterdam, the Netherlands: CILSS and Vrije University.

Sawadogo, H., and M. Ouedraogo. 1996. *Une technologie paysanne pour une agriculture durable: Le zaï.* INERA/RSP/Nord Ouest Burkina Faso. Projet ASP/SADAOC. Groningen, the Netherlands: Université de Groningen.

Sawadogo, H., F. Hien, A. Sohoro, and F. Kambou. 2001. Pits for trees: How farmers in semi-arid Burkina Faso increase and diversify plant biomass. In *Farmer innovation in Africa: A source of inspiration for agricultural development*, ed. C. Reij and A. Waters-Bayer. London: Earthscan.

Slingerland, M. A., and V. E. Stork. 2000. Determinants of zaï and mulching in north Burkina Faso. *Journal of Sustainable Agriculture* 16 (2): 53–76.

Smale, M., and V. Ruttan. 1994. *Cultural endowments, institutional renovation, and technical innovation: The "Groupements Naams" of Yatenga, Burkina Faso.* Bulletin Number 94-2. St.Paul, Minn., U.S.A.: Economic Development Center, Department of Economics, University of Minnesota.

Taonda, J.-B., F. Hien, and C. Zango. 2001. Namwaya Sawadogo: The ecologist of Touroum, Burkina Faso. In *Farmer innovation in Africa: A source of inspiration for agricultural development,* ed. C. Reij and A. Waters-Bayer. London: Earthscan.

Tappan, G., and M. McGahuey. 2007. Tracking environmental dynamics and agricultural intensification in southern Mali. *Agricultural Systems* 94: 38–51.

Taylor, G., and B. Rands. 1992. Trees and forests in the management of rural areas in the West African Sahel. Desertification Control Bulletin 21: 49–51.

Tougiani, A., C. Guero, and T. Rinaudo. 2009. Success in improving livelihoods through tree crop management and use in Niger. *GeoJournal* 74 (5): 377–389.

Wentling, M. 2008. *Niger—Annual food security report and future prospects*. Niamey, Niger: U.S. Agency for International Development.

WRI (World Resources Institute). 2008. Turning back the desert: How farmers have transformed Niger's landscapes and livelihoods. In *Roots of resilience: Growing the wealth of the poor*. Washington, D.C.: World Resources Institute.

Wright, P. 1985. Water and soil conservation by farmers. In *Appropriate technologies for farmers in semi-arid Africa,* ed. H. W. Ohm and J. G. Nagy. Purdue, Ind., U.S.A.: Purdue University, Office of International Programs in Agriculture.

Yamba, B. 1995. *Ressources ligneuses et problèmes d'aménagement forestier dans la zone agricole du Niger*. PhD dissertation, Université de Bordeaux, France.

Yamba, B., M. Larwanou, A. Hassane, and C. Reij. 2005. *Niger study: Sahel pilot study report.* Washington, D.C.: U.S. Agency for International Development and International Resources Group.

Younger, S., and E. G. Bonkoungou. 1984. Burkina Faso: The Projet Agro-Forestier—A case study of agricultural research and extension. In *Successful development in Africa*, ed. R. Bheenick et al. Washington, D.C.: World Bank.

Zombré, N. P. 2003. *Les sols très dégradés (zipellé) du Centre Nord du Burkina Faso: Dynamique caractéristiques morpho-bio-pédologiques et impacts des techniques de restauration.* PhD dissertation, Université de Ouagadougou, Burkina Faso.

Zougmoré, R. B. 2003. *Integrated water and nutriment management for sorghum production in semi-arid Burkina Faso.* Tropical Resource Management Papers 45. PhD dissertation, Wageningen University, Wageningen, the Netherlands.

IFPRI DISCUSSION PAPERS
Prepared for the "Millions Fed: Proven Successes in Agricultural Development"

910. *Combating stem and leaf rust of wheat: Historical perspective, impacts, and lessons learned.* H. J. Dubin and John P. Brennan, 2009.

911. *The Asian Green Revolution*. Peter B. R. Hazell, 2009.

912. *Controlling cassava mosaic virus and cassava mealybug in Sub-Saharan Africa.* Felix Nweke, 2009.

913. *Community forestry in Nepal: A policy innovation for local livelihoods.* Hemant Ojha, Lauren Persha, and Ashwini Chhatre, 2009.

914. *Agro-environmental transformation in the Sahel: Another kind of "Green Revolution."* Chris Reij, Gray Tappan, and Melinda Smale, 2009.

915. *The case of zero-tillage technology in Argentina.* Eduardo Trigo, Eugenio Cap, Valeria Malach, and Federico Villarreal, 2009.

916. *Zero tillage in the rice-wheat systems of the Indo-Gangetic plains: A review of impacts and sustainability implications.* Olaf Erenstein, 2009.

917. *The impact of shallow tubewells and boro rice on food security in Bangladesh.* Mahabub Hossain, 2009.

918. *Hybrid rice technology development: Ensuring China's food security.* Jiming Li, Yeyun Xin, and Longping Yuan, 2009.

919. *Pearl millet and sorghum improvement in India.* Carl E. Pray and Latha Nagarajan, 2009.

920. *Institutional reform in the Burkinabè cotton sector and its impacts on incomes and food security: 1996–2006.* Jonathan Kaminski, Derek Headey, and Tanguy Bernard, 2009.

921. *Private sector responses to public investments and policy reforms: The case of fertilizer and maize market development in Kenya.* Joshua Ariga and T. S. Jayne, 2009.

922. *The mungbean transformation: Diversifying crops, defeating malnutrition.* Subramanyan Shanmugasundaram, J. D. H. Keatinge, and Jacqueline d'Arros Hughes, 2009.

923. *The global effort to eradicate rinderpest*. Peter Roeder and Karl Rich, 2009.

924. *Rural and urban linkages: Operation Flood's role in India's dairy development.* Kenda Cunningham, 2009.

925. *Rich food for poor people: Genetically improved tilapia in the Philippines*. Sivan Yosef, 2009.

926. *"Crossing the river while feeling the rocks:" Incremental land reform and its impact on rural welfare in China.* John W. Bruce and Zongmin Li, 2009.

927. *Land-tenure policy reforms: Decollectivization and the Doi Moi System in Vietnam.* Michael Kirk and Tuan Nguyen, 2009.

928. *Improving diet quality and micronutrient nutrition: Homestead food production in Bangladesh*. Lora Iannotti, Kenda Cunningham, and Marie Ruel, 2009.

929. *Improving the proof: Evolution of and emerging trends in impact assessment methods and approaches in agricultural development.* Mywish K. Maredia, 2009.

For all discussion papers, please go to www.ifpri.org/pubs/pubs.htm#dp.
All discussion papers can be downloaded free of charge.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

www.ifpri.org

IFPRI HEADQUARTERS

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA

P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI

CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org