Synergies between Natural Resource Management Practices and Fertilizer Technologies:

Theory and Practice

by

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1. Introduction

Successful agricultural development has resulted in substantial alleviation of poverty and food security in Asia and Latin America since the 1960s. In Sub-Saharan Africa (SSA), however, productivity levels have remained stagnant. Many scientists argue that low soil fertility is the primary biophysical constraint blocking agricultural development in SSA.

Soil fertility problems in SSA can be attributed to soil degradation due to soil mining (associated with long-term low-input agriculture), tillage, and accelerated erosion. Soil organic matter (SOM), soil organic carbon (SOC), and nutrients have become depleted in most soils. In the lower rainfall regions of the continent, the situation is analogous to the "Dust Bowl" era in US history when SOM levels reached their lowest point after years of agriculture-induced soil degradation. In these regions of SSA, wind and water erosion are depleting what little remains of the topsoil, leaving farmers with low-fertility subsoils or encroaching deserts, declining or stagnant yields, and long-term poverty. Fertilizers are considered by many to be critical tools for increasing crop yields and restoration of soil fertility in SSA. But farmers in SSA have not adopted fertilizer in a sustainable manner. Unfavorable and volatile input/output price ratios, poor crop response, poorly developed markets, and inappropriate marco-economic and sectoral policies have all been blamed for low fertilizer adoption rates. Given the seemingly insurmountable problems associated with fertilizer promotion in SSA, many have argued that the solution to soil degradation and agricultural productivity problems lies in the promotion of better natural resource management (NRM) practices (e.g., agroforestry, anti-erosion measures, better use of organic amendments). Yet, here too adoption has been slow- high labor demands for many techniques combined with small and deferred yield and income benefits are the most frequently noted constraints.

In this paper we argue that a holistic approach offering farmers a broad menu of crop options (e.g., both commercial and subsistence crops) and a wide range of improved techniques (e.g., both fertilizer-based technologies and NRM practices) could speed up adoption of all types of improved practices and technologies thereby promoting rapid growth in farm productivity and incomes. Although there is an extensive body of technical literature supporting such an approach, many extension efforts in SSA continue to focus on a limited set of crops and promote either NRM or fertilizer-based technologies.

This paper uses two case studies from Mali to critically review different approaches to resolving African soil fertility and agricultural production problems. The review focuses on identifying the characteristics of the programs that either promote or constrain the adoption of improved production techniques. The programs are managed by the Office de la Haute Vallée du Niger (OHVN) natural resource management division and Sasakawa Global (SG) 2000. The OHVN is a regional development program (formerly a parastatal) that provides a wide range of extension and support services to farmers under its jurisdiction. We focus on OHVN's NRM program which is charged with introducing NRM practices into a cotton/coarse grain cropping system where farmers are already accustomed to using purchased inputs such as fertilizers and pesticides. The SG program is designed to introduce fertilizers and pesticides into a predominantly subsistence coarse grain (millet/sorghum) cropping system that includes some production of groundnuts and cowpeas which are marketed to a limited extent.

Before turning to the case studies, we present a brief overview of what the soil science and agronomic literature has to say about the synergies of fertilizer-based technologies, organic amendments, and natural resource management practices. Section 3 begins with some general background information about Mali and then describes the characteristics of the case study programs, presents information on farmers' responses to the programs, and summarizes key lessons learned. Section 4 concludes with ideas on moving forward with efforts to promote increased adoption of all types of improved production technologies.

2. The Need for a Holistic Approach: Theory and Technical Evidence[1]

2.1. Understanding the Carbon Cycle and Net Primary Productivity

There is a growing consensus regarding the need to use fertilizer, organic amendments, and appropriate management practices in an integrated manner. Fertilizer and organic matter each contain nutrients required by plants to create biomass via photosynthesis, but fertilizer alone makes very little (if any) direct contribution to soil macro-structure, increased water-holding capacity, improved infiltration and erosion control, prevention of soil hardening, or improved nutrient holding capacity. When combined with recycling of organic materials, the primary positive impact of fertilizers is to increase the biological base of the plant/soil system resulting in increased crop yields and recapitalization of soils. When fertilizers or organic inputs are applied, essential nutrients are supplied for the creation of plant biomass by means of photosynthesis. In the process, CO_2 is incorporated or fixed into the biomass from the atmosphere which is then referred to as organic C. When fertilizers are applied, the increased availability of nutrients to the plant creates an increased capacity for absorption of the basic ingredients (sunlight, water, atmospheric CO_2, and nutrients) used in the process of producing plant biomass, thereby increasing the biology and productivity of the soil system.

The biological health and sustainability of an ecosystem is typically assessed by its net primary productivity (NPP). This is "the amount of plant biomass produced during a given time period within a particular ecosystem. In parts of SSA such as the Sahel, NPP is severely limited due to 'sub-optimal' conditions which result in low biomass, SOM, nutrients and water levels. Rates of growth of plants and crops are three to five times less than the maximum 'production potential' which could be achieved if nutrients and water were not limited. NPP is also limited due to the short season of rapid growth (Penning de Vries and Djiteye 1991). Fertilizer, used with organic

[1] This section draws heavily on Weight and Kelly (1999) which presents a much more detailed discussion of technical and economic issues concerning organic and inorganic fertilizer use in SSA, with attention being given to both the positive and negative effects of both.

amendments and appropriate management practices (e.g., no-till as practiced in the U.S. and L.A.), can help mitigate these constraints.

2.2. Developing Holistic Systems

Recent research and writings support the use of fertilizers in combination with organic inputs as part of intensification strategies to drive sustainable productivity growth and end the long cycle of agricultural and economic stagnation in SSA (Bationo and Mokwunye1991, Bekunda, Bationo and Ssali, 1997, Breman and Sissoko, 1998, Pieri, 1992, Quinones, Borlaug, and Dowswell, 1997; Reardon, 1997; Swift, 1996; Wallace, 1997; Yanggen et al. 1998, Weight and Kelly 1999). There is a consistent perspective, in these works, that neither input strategy, on its own, is capable of achieving production goals and food security.

While it is technically possible for a individual farmer to use only organic inputs and have sufficient nutrients to attain yields that would meet food security and income goals, most African farmers need to recapitalize their soils for long-term sustainability. If one were to calculate the amount of organic inputs (manure or plant material) that is required to satisfy both crop demands and recapitalization requirements, the total would be enormous.[2] Hence, it would be imprudent for a government to recommend such a strategy on the national level given inadequate supplies of organic resources. Fertilizers must be promoted as a concentrated, complementary source of nutrients to meet these plant/soil needs, yet fertilizer alone is not able to improve SOM.

It is important to note that a sustainable system in SSA requires not only SOM and nutrients but also careful attention to four other parts of the cropping system: tillage methods and residue management, water management, erosion control, and pest management. When farmers are offered a menu of techniques such as fertilizer, organic inputs, conservation tillage, cover crops, rotations, agroforestry, and integrated pest management; they are capable of addressing the broad range of constraints that they face: especially (i) soil mining due to low input agriculture, (ii) low rainfall levels, (iii) poor soil structural stability resulting in very low water and nutrient-use efficiency as well as crusting and sealing, (iv) accelerated rates of decomposition due to tillage, (v) lack of vegetative cover with increased erosion and soil temperatures and (vi) pest attacks that may even increase as SOM and productivity increase. Holistic systems address these constraints in the following ways: Providing ecologically based recapitalization strategies with long-term build-up and stabilization of SOM addresses constraints (i), (ii), and (iii); minimum tillage addresses constraint (iv); providing vegetative cover near the soil surface addresses constraint (v); and integrated pest management addresses constraint (vi). The most critical factor for the implementation of these practices will be that these systems provide economic and other critical benefits to farmers (Weight and Kelly, pg.48-49).

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[2] For example, 16-47 hectares of grazing land might be required to produce enough manure for a hectare of land producing 1-3 tons of maize (Giller et al. 1997); 20 tons of leaf biomass with 80% moisture and 2.5% N would be required to substitute for 100 kg of N (Sanchez et al. 1997)

We now turn to the Malian case studies to illustrate the extent to which they are engaged in the type of holistic approach described above.

3. Two Case Studies from Mali

3.l. Mali : A Conducive Environment for Technology Adoption and Agricultural Intensification

Agricultural productivity growth based on the adoption of improved technologies does not take place in a vacuum; farmers adopting new technologies are influenced by the physical, political, and socio-economic environment in which they live. Both case studies are in Mali where recent reforms have made the general environment quite favorable for technology adoption.

Agricultural systems include pastoral livestock production in the Sahel, semi-subsistence millet/sorghum production in close proximity to highly commercialize irrigated rice perimeters in the Sudanian zone, and market-oriented cotton and coarse grain production in the South Sudanian and Guinean zones, where fertilizer and pesticides are used extensively.

During the last two decades Mali implemented reforms aimed at transforming its economy: the dismantling and sale of some state enterprises, the extensive reform of others, and the removal of many barriers to trade. Private businesses as well as independent farmer and trade organizations are now able to compete in areas formerly reserved for the state. The liberty of association and expression also improved as a result of the democratization movement begun in 1991. The 1994 devaluation of the CFA franc provided a major stimulus to the cotton, rice, livestock and horticulture sectors. Although Mali remains one of the poorest countries in the world with a GDP/capita of $250 in 1998 (equal to $720 using purchasing power parity estimates), the economy has recently been growing more rapidly than the population (4.6% vs. 2.8%).

Soil degradation is a concern throughout the country, but particularly in the productive southeast where some studies have estimated annual nutrient depletion rates as high as 25 kg/ha of nitrogen and 20 kg/ha of potassium, 40% of which is lost through erosion and leaching (van der Pol 1990, van der Pol and Traoré 1993). Loss of soil organic matter is also a serious problem, even when manure and fertilizers are used. There is ample evidence from agronomic research that Malian farmers can raise yields by adopting improved cultivars, fertilizers, and a variety of NRM practices (Henao et al.1992). Unfortunately, the vast majority of Malian farmers are not yet using these improved techniques. Hence, the question of what is being done in Mali to encourage widespread adoption of technologies that will increase productivity and incomes, while protecting the soils from further degradation, is a timely and important one.

3.2. Overview of Case Study Zones, Objectives, Resources, and Philosophies

3.2.1. The OHVN NRM Program

Production environment. The OHVN extends across four agro-ecological zones (Sahelian, North and South Sudanian, and Sudano-Guinean) with rainfall ranging from a low of 400-900 mm in the Sahelian zone to 1000-1200 mm in the Sudano-Guinean zone. The soils (predominantly ferric luvisols) are characterized by high erosion and degradation with deforestation a contributing factor. The consequence–low yields and incomes–have stimulated high rates of out-migration from the zone. Millet and sorghum production predominate in the rainfed areas, but there is cultivation of cotton, tobacco, and peanuts where the agro-ecology is favorable and some irrigated rice. The zone is important due to its proximity to Bamako but it represents a small share of aggregate national production (5.5% of cotton, 2.3% of coarse grains, and 3.5% of rice). Use of purchased inputs is high on cotton, which represents 25% of area cultivated, but low for other crops. Ownership of plowing equipment is growing in the zone but still low compared to the traditional cotton basin (.6 traction units per OHVN farm v. 1.2 units in the southeastern zones managed by the Compagnie Malienne pour le Développement des Textiles or CMDT).

The NRM Program. The NRM program began in the late 1980s but did not take off until the early 1990s when donor support increased. The broad goal of the NRM program is to train communities in improved NRM and crop production techniques so that they will realize increased levels of food security and monetary income while ensuring continued access to adequate supplies of water, wood, and pasture for animals. In a dynamic sense this means continuous improvements in crop productivity and the renewal of natural resources over time.

The NRM program has focused on the eastern and southern parts of the OHVN where rainfall exceeds 800 mm/year and there is a history of cultivating cash crops (primarily cotton at present). Following the 1994 devaluation and a rise in world cotton prices, the cotton company (CMDT) removed an earlier restriction on the amount of inputs an individual farmer could obtain on credit. This led to rapid expansion of cotton in the oldest part of the cotton zone to the southeast of the OHVN; area increased 25% annually from 1994-1997 and production by 21% per year. Yields, however, declined (-3.1%) (Tefft 2000, forthcoming).

As yields declined in the older production zones, the CMDT began more active promotion of production in the OHVN, even in some areas where cotton had not been considered profitable. Between 1993/94 and 1998/99 OHVN cotton area grew from 8624 to 35816 hectares, production rose from 10,684 to 33,740 tons. Aggregate yields, however, followed the same trend as in the CMDT zone, declining from 1239 to 942 kg/ha (OHVN statistics). These declining yield trends cannot be explained by rainfall. Conventional wisdom holds that it is due to lower fertilizer and pesticide doses per hectare and expansion to marginal lands.

The link between cotton and NRM is important because one of the underlying tenets of the OHVN program is that there needs to be a strong economic incentive if NRM techniques are to be adopted by farmers. Thus far, that economic incentive has been the opportunity to increase household income through cotton production on improved land. This focus on cotton producers is a unique aspect of the OHVN/NRM program as many NRM programs target semi-subsistence farmers considered too poor to purchase improved inputs such as fertilizers and pesticides.

The NRM program has focused on the use of a participatory approach. The first actions taken by NRM staff were field visits aimed at helping communities to recognize the environmental problems they were confronting, understand what was causing them, admit that there was a link between their current agricultural practices and the growing environmental problems, and develop action plans for dealing with the problems. After the initial visits, the NRM program only intervened in communities that were openly receptive to making changes and willing to invest human and/or financial resources in these changes. In some villages, this meant a delayed start to the NRM program because communities needed to deal with basic training and organizational issues first (e.g., forming a village association if it did not exist, obtaining literacy training for association members so that records could be kept and credit applications could be prepared, etc.).

Assistance with literacy and numeracy training was provided by the national literacy training program in collaboration with OHVN and assistance with organizing village associations came largely from a CLUSA (Cooperative League of the U.S.A.) project (funded by USAID as part of their overall assistance package to the OHVN). There is also a strong link between the NRM program and the Département de Recherche sur les Systèmes de Production Rurale at the Institut d'Economie Rurale where research has been conducted to identify and test both NRM and seed/fertilizer technologies.

Once a village (or group of villages) is selected to participate in the NRM program, OHVN agents train a technical team composed of approximately 5-10 villagers (selected by their peers) who have completed literacy training programs and are willing to devote one day per week to learning NRM techniques, training others in the village, organizing community level NRM activities, and keeping records of both individual and community NRM activities. The team members receive no salary or special benefits from OHVN, but most are remunerated (usually in kind rather than with cash) by their communities. Most team members are relatively young farmers–an interesting change to observe in a society where leadership roles have traditionally been held by village elders.[3] Priority is given to training village technical teams in the NRM themes selected by villagers, with training in other themes coming later. After the training, OHVN extension agents continue to provide support to the team as it helps individual farmers and community groups implement their programs. The goal is to promote village-run extension services. At present 20 villages have attained this status.

[3]The requirement of literacy may be driving this as younger farmers tend to be more responsive to the literacy training program than older ones.

3.2.2. The Sasakawa Global 2000 Program

Production environment. Mali's SG program began in 1996 in the regions of Segou, Mopti, and Koulikoro, primarily in areas of these regions not served by major development projects such as OHVN. SG zones are characterized by Soudanian climates, but border on Sahelian zones in the north and Guinean zones in the south. Typical rainfall since the beginning of the program ranged from 400-800 mm (lower than in the OHVN). Soils are similar to soils in the OHVN. Commercial crops and markets (e.g. peanuts, tobacco, cotton) are not well developed in areas of SG intervention; rainfed millet/sorghum systems predominant and some maize is produced in higher rainfall areas.

The SG Program. The SG program in Mali has three themes: (1) restoring and improving soil fertility through the promotion of improved fallows using nitrogen fixing legumes and natural phosphates; (2) intensification of cereal production using improved seeds, pesticides, fertilizer, and cultural practices; and (3) formation of savings and loans associations to enable participants to finance input acquisition after then end of the SG program. The Mali program is part of an Africa-wide program characterized by:

- ⇨Close collaboration with ministries of agriculture in lieu of developing stand-alone programs.
    - ➻Extension programs are jointly designed and implemented using ministry personnel as field agents; SG also works with local research institutes and other development organizations to support the extension program.
- ⇨Exclusive attention to food crops.
- ⇨Focus on restoring and maintaining soil fertility.
    - ➻Although often characterized as promoting exclusively Green Revolution type seed/fertilizer technologies, SG programs often promote a range of organic and mineral fertilizers, including promotion of manure, compost, agroforestry techniques, natural phosphates and the introduction of bulk blend fertilizers to reduce costs of providing external nutrients.
- ⇨Promotion of savings and loan associations to provide a vehicle for access to inputs and credit.
- ⇨Direct farmer participation in technology transfer through farmer managed test plots.
    - ➻SG demonstrates to farmers the benefits of adopting improved technologies through the promotion of 0.5 (or 0.25) hectare test plots that are cultivated by participant farmers along side a plot using the farmer's normal practices. This side-by-side cultivation using normal and SG methods permits farmers to easily evaluate the difference in yield between the two plots and decide if they want to continue using the SG technology.
- ⇨Promotion of intensification using appropriate, financially viable technologies.
    - ➻The sustainability (both financial and environmental) of technologies promoted by SG has been the object of much heated debate (e.g., Jiggens, Reijntjes and Lightfoot 1996, Easterbrook 1997, Winrock International 1997), stimulating SG to focus more intensively on this issue in recent years by developing collaborative arrangements with other institutions that have been assisting with profitability analyses and projections (e.g., Howard et al. 1998 and 1999, Nubukpo et al., 1999).

SG's Mali program is one of its first efforts to introduce seed/fertilizer technologies into the drier, riskier, production systems of W. Africa where the yield potential for the most common coarse grains is low. For example, in Mali millet yields of 300-700 kg/ha can be expected using traditional technologies and 800-1200 kg/ha using improved technologies while in Benin where SG has previously worked, maize yields of 1000 kg/ha with traditional techniques and 3000 kg/ha with SG techniques are the norm.

This case study focuses on one part of the SG Mali program–the 1998 millet intensification program in the Segou Region. In 1996 and 1997, SG promoted improved fallows in the region (dolichos and phosphate rock from local sources–PNT). Farmers used the improved fallows as long as they were able to recover costs by selling seed to SG. When SG stopped purchasing seed in 1998, demand for the technology fell abruptly and the millet intensification program became more popular. A focus on millet is important as the Segou region accounts for 35% of national millet production.

3.3. Farmers' Response to the Programs and Their Perceptions of Them

Because information on the OHVN and the SG 2000 programs come from unrelated studies, there is a lack of strict comparability in the information presented below. Some information is from official OHVN or SG 2000 service statistics, some from a February 2000 rapid appraisal conducted by two of the authors in seven OHVN villages (six with strong NRM programs and one just getting started), and some from a 1999 INSAH survey of SG participant farmers in which two of the authors were involved. Only after the survey and rapid appraisal were completed did the idea of documenting the two case studies arise.

3.3.1. Response to the OHVN NRM Program

Table 1 is a summary of what OHVN refers to as the 'physical' results of their program. It shows the 1996-99 adoption in physical measures (e.g., meters, hectares, number) of 22 themes. The table shows that anti-erosion techniques (rock lines, gully plugs, contour plowing, vegetative bands) and improved organic matter (manure and compost pits) are among the more popular themes. Growth in permanent livestock stabling (the pinnacle of improved manure management) is slow due to the high costs (construction of holding pens and high labor demands for transporting animal feed), but highly appreciated.

Table 2 shows that since the program began recording adoption statistics in the early 1990s, 60% of villages and 47% of farms have adopted one or more of the proposed NRM themes. A major accomplishment has been the restoration of abandoned or severely degraded fields–estimated to represent approximately 17% of the total cultivated area in 1999. Approximately 3900 farms have been able to fix their cultivated area for at least three years (i.e., no clearing of new land) while maintaining or increasing production.

Although OHVN does not keep statistics on the characteristics of the farms having adopted NRM practices, the rapid appraisal mission noted that farmers who had been in the program from the early years and had adopted a wide range of practices tended to be among the better-off farmers in their villages (more land, livestock, animal traction equipment, etc.) both before and after adoption. This suggests that NRM practices, like fertilizer-based technologies, are adopted first by wealthier farmers, raising questions about the argument that NRM practices should be targeted to the poor who cannot afford expensive purchased inputs.

To date, there is no evidence that NRM adoption has had a positive impact on aggregate yields in the OHVN. Table 3 reveals strong growth in area cultivated and production but stagnant or negative yield trends for cotton, millet, sorghum, and maize. Appparently, the degree of adoption is not yet high enough for the favorable results being achieved by participant farmers and documented in numerous case studies to be reflected in the aggregate numbers. Table 4 summarizes some yield trend data shared with us by farmers who had adopted anti-erosion practices in combination with improved organic matter.[4] It is encouraging to see that the average yields obtained by these farmers during the 1990s exceed the average yields reported in OHVN statistics for every crop; the differences were greatest for maize and cotton–the two crops that benefit most directly from applications of fertilizer and organic amendments that are used more intensively once land is stabilized through the adoption of anti-erosion practices.

The February 2000 rapid appraisal that covered seven OHVN villages and included discussions with about 100 farmers representing adopters as well as non-adopters confirmed that the experiences of the individual farmers reported in Table 4 were not isolated cases. Specific examples of progress reported by in rapid appraisal discussion groups are summarize below.

⇨Yields of all crops are increasing for farmers adopting NRM intensification methods.
- ➻Six of seven villages visited provided numerous illustrations from extension and individual farmers' records..

⇨Village youth are staying at home to farm rather than migrating.
- ➻This was very evident in all villages visited; youth were present at all meetings, they play important roles in management of farmer associations, and they were very active participants in rapid appraisal discussions.

⇨Farmers are investing heavily in agricultural equipment, traction animals, and livestock
- ➻When asked what they were doing with their increased incomes, the most common response was investment in equipment and/or livestock

⇨Farmers are diversifying, with many new forays into dry season crops and tree crops.
- ➻Increased production of horticultural products during the dry season (green beans for Europe, onions/tomatoes and bananas for Bamako, possible increases in sorrel production for export to the US) is one of the reasons for the reduction in outmigration; marketing

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[4]Farmers who have received literacy training often keep their own records of yields, input use, and investments while members of the village technical teams (*animateurs*) keep records for other farmers (particularly for the early adopters). Cereal yields are base on number of sacks of threshed grain harvested. Cotton yields are based on sales receipts.

remains a problem here, but the farmers' associations appear to have a level of management skills permitting them to deal with the setbacks and move ahead (vs. the old days when they would be expecting the government to bail them out).

- Tree crop production (particularly teak for production of construction poles) through the development of village and private wood lots is expanding slowly, but most examples seen during the rapid appraisal had not yet begun to generate income.

⇨Farmers are unanimous that life is better now than 10 years ago.

- They eat better (more food and better variety)
- They dress better
- They travel more easily (mobylettes have replaced bicycles in many cases)
- Schools and health services are more accessible
- They are better educated (literacy programs and CLUSA management training)

⇨Farmers are optimistic and enthusiastic about the future.

Table 5 presents a comparison of returns to land cultivated between 1990/91 and 1998/99 with and without the adoption of NRM practices fo a millet/cotton rotation (A) and a cotton/millet rotation (B). The *without* scenario assumes a constant annual rate of decline in both cotton (3%) and millet (2%) yields based on recent aggregate trends for Mali. The *with* scenario uses yield data recorded by an OHVN farmer with assistance from members of the village technical teams (*animateurs)*. Although we have a list of the themes adopted by the farmer (rock lines, vegetative bands, plowing perpendicular to the slope, "grattage à sec", manure, fixation of plots, end of season plowing), we do not have good estimates of costs. Consequently, the analysis calculates the present value of the difference in total production between the two scenario during nine years, using optimistic and pessimistic price assumptions.

Millet grown using NRM practices produced an average of 414 kg/ha more grain each year than our estimate of millet grown without NRM; the difference for cotton was 486 kg/ha. The rotation that began in 1990 with millet (rotation A) obtained much better results than the rotation that began in 1990 with cotton (rotation B). These differences are due entirely to inter-annual variations in yield. Using a high-price scenario, and a discount rate of 10%, the present value of the additional production from the NRM millet/cotton rotation was 342,300 and 151,100 FCFA respectively for rotation A and B; with the low price scenario, the results were 288,600 and 126,300 FCFA respectively. Most of the costs of the practices used by this farmer were costs of family or community labor, so we converted the returns to labor-day equivalents at the current agricultural wage rate of 750 FCFA/day. Using the high-price scenario we get a range of 201 to 456 labor days; using the low-price scenario gives 168-385 labor days. It is unlikely that the labor having gone into the NRM practices during the 9 years exceeded these returns.

It is helpful to contrast the enthusiasm of NRM program participants with farmers visited in one village that was just beginning cotton production (4 farmers had just completed their first harvest) and had not yet benefitted from literacy training, CLUSA management training, or the NRM program. Farmers in this village presented the rapid appraisal team with the traditional long list of all the things the government and donors could do for them because they were so poor; this was in sharp contrast to the NRM/cotton villages where farmers told the team members about their plans for future investments and ideas for crop diversification–never suggesting that they needed handouts to realize these plans. Even if the rapid appraisal results are not fully representative of the entire zone, it is clear that there is important progress being made in many NRM/cotton villages and important lessons to be learned about what has been driving the changes.

The rapid appraisal team noted that this progress is the result of a complex process that has been going on for 15-20 years. It is the result of multiple efforts by many actors. USAID has been a dominant actor, providing OHVN with an important source of external financing since the 1980s.[5] The Institut d'Economie Rurale (IER) has done extensive research on both NRM practices and fertilizer to build up the menu of themes that can be recommended to farmers. Important contributions have also come from the Germans who are supporting NGO activities. This anti-erosion program (PAE) is focusing on the development of a 'gestion de terroir' approach that gives high priority to improving village-level management of a community's natural resources. In addition, there are an estimated 20-30 NGOs operating in various capacities in the OHVN (not all operating in the agriculture or NRM sector). Based on information gathered during the rapid appraisals, discussions with USAID and OHVN personnel, and documents reviewed, the key ingredients contributing to current progress appear to be:

- Good identification of *a broad list of technologies* capable of increasing yields
- Potential for increased cash income from expansion of *cotton* production
- *Community* approach to implementation
- Focus on *youth*
- Focus on villages/farmers most *likely to benefit* from GRN actions
- Use of *demonstration effect* thru model farmers and model villages
- *Incremental training* (literacy, technical skills, community organization, management skills using the CLUSA model)
- *Support services* offered
    - Improved feeder roads (funded through the USAID project)
    - Credit guarantees for a limited period following management training
    - Input/output transport assistance
    - Regular supervision and support to trainees
    - Some free equipment for implementing NRM activities
    - Market research by OHVN to help with crop diversification

Among the factors listed above, three stand out as being absolutely essential for sustainable adoption of an holistic approach to agricultural production that includes both NRM practices and improved inputs:

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[5] A review of Proces Verbal (OHVN August 98) showed USAID annual contributions to the OHVN budget ranging from $200-500,000 between 1995/6 and 1998/99, with a planned increase to $1.3 million for support of the agribusiness unit of OHVN in 1999/2000.

- A profitable cash crop with reliable markets and stable prices.
- Improved, affordable technologies that benefit both cash and food crops.
- Training programs that equip young farmers with the literacy and management skills needed to function as effective commercial farmers, both independently and in associations.

3.3.2. Response to the Sasakawa Global 2000 Program in Segou Region

Approximately 100 farmers participated in the survey of SG participants in the Segou Region. A review of the characteristics of the household heads interviewed suggests that they are among the better educated and wealthier farmers in the zone (43% were literate, average farm size was 10 hectares, average assets included 3.7 traction animals, 1.8 plows/cultivators, and 1.2 carts). In addition, 26% had been participants in other types of demonstration or model farmer programs. Although participants appear to be among the better-off farmers in the zone, the zone is not a wealthy one. Farmers are heavily dependent on millet–a low-value, low-productivity crop–for income. Eighty-eight percent of farmers claimed that millet production represented more than 50% of their total income (cash and in-kind); 37% of this group declared that millet represented at least 75% of total income. In addition, only 27% claimed to have other sources of income (e.g., livestock or non-farm activities) on which they could rely to repay input credit should their millet crop fail.

The millet intensification program in Segou offers three incremental levels of improved technology representing increasing costs, risks, and yields. This incremental approach permits farmers to move gradually from current practices to input-intensive practices, improving their skills and financial capacity to work with new technologies year by year. The three themes were:

Level A:	improved seed and mildew protection,
Level B:	package A plus light/low-cost fertilization using improved compost,
Level C:	package A plus heavy/higher-cost fertilization.

Because mildew can destroy as much as 60% of a millet crop, the Level A package is an anti-mildew treatment called Apron+ and a short-cycle seed variety. Moving up to level B, farmers currently using compost pits (a theme promoted by the government's training and visit extension program) can improve their compost by adding locally produced phosphate rock (PNT). Although some farmers successfully used this theme in 1996 and 1997, many do not have compost pits or found the costs of the PNT a constraint. In 1998, SG did not have the financial resources to adequately promote both Level B and Level C technologies, so they focused on the latter. Level C–for farmers having tried the first two levels as well as those willing to move directly to this level–consists of improved seed, Apron+, compost, 25 kg/0.25 ha of natural phosphate (PNT), and 25 kg/0.25 ha of NPK (bulk-blended 23-13-13 with S/MgO/Zn).

During the 1999 survey, farmers were asked to identify the three most important risk factors constraining their production. In this zone one tends to think of poor rains as the major constraint, but farmers gave slightly more importance to the problem of unreliable access to inputs (score of 132 for inputs vs. 116 for rain[6]), with bird damage and declining soil fertility coming in third and forth positions (scores of 92 and 64). Having identified the three principal factors thought to increase production risk, farmers evaluated the extent to which SG technologies were alleviating these problems. Their replies strongly contradicted the conventional wisdom that use of external inputs (particularly expensive fertilizers) increases risk; most participants (96%) claimed that the SG technologies **reduced** the risk of crop loss associated with the above mentioned problems; only 3%–all Level C farmers–viewed the technologies as risk augmenting.

Farmers were asked to explain their perceptions of the SG technologies' impact on risk. The most common reply (62%) was that the entire combination of inputs diminished the risk of getting very low millet yields. Reduction of risk due to attacks by birds, rats, and termites was the next most common reply (16%); apparently the Apron+ repels insects and animals. Several farmers (8%) commented that SG technologies reduced risks associated with poor access to land because they could increase yields on existing land. Reduction of risks associated with poor rains was mentioned by 5%–primarily a reference to the shorter cycle seed varieties. The key concern of the 3% of farmers indicating that SG technologies increased risk was the problem of not being able to pay back the credit for the relatively expensive Level C package.

Crop budgets estimated from survey data collected for the SG participants' test and control plots. (Table 6) show that returns for Level A technology were much greater than for Level C. All Level A farmers realized positive returns. The value/cost ratio for the package is 10 and the average net benefit was 9615 FCFA. This net benefit is the equivalent of what one would earn by hiring out labor services for 13 days at the prevailing agricultural wage rate (750 FCFA/day)! Farmers were unanimous in their praise for this package – all agreed it was profitable and reduced risk. Average returns to the Level C package were 3858 FCFA and the value/cost ratio only 1.5. Although a common rule of thumb is that a v/c must be at least 2 to stimulate demand from a technology package (even 3 or 4 in risky environments like the Sahel), 53% of the farmers thought the package was profitable. The average return masks a high degree of variability. Ten farmers had losses ranging from 1000 to 9000 FCFA. Surprisingly, four of these ten farmers declared the package profitable (all four had losses less than 5000 FCFA). Among the farmers with positive returns, 43% either found the package unprofitable or only marginally so ("passable"); returns for this group were in the 500-10,000 FCFA range. The five farmers with returns greater than 10,000 FCFA were unanimous that the package was profitable.

A shortcoming of this partial budget analysis based on only one year of results is the treatment of the PNT. It is unlikely that the PNT would have provided a yield response in the year it was applied as it tends to be released slowly over time, but the full cost of the PNT must be paid in the year of application. A multi-year analysis of the package capable of measuring residual PNT effects would raise the profitability. SG needs to find ways of helping participants monitor the

[6] Scores reported are weighted frequencies: the most important problem received a weight of 3, the second 2, and the third 1.

PNT effect because many farmers were so unimpressed that they recommended SG discontinue its promotion.

The relatively high percent of farmers losing money (38%), of whom half harbored the misconception that the package was profitable, raises challenging policy and research questions. Should extension services be helping farmers evaluate profitability as economists do (i.e., looking at marginal returns to test plots)? Should economists be trying to better understand profitability criteria used by farmers? Are they using different objective functions such as maximizing production rather than income? If farmers believe that technologies are profitable when they are not, will they be likely to request more input credit than they are able to reimburse? Although we do not have full information on credit reimbursement, at the time of the surveys the level A farmers had reimbursed all of their credit but many of the level C farmers had outstanding debts owed to SG.

Given that SG efforts to introduce improved techniques to Segou cereal farmers is in its infancy (3rd year of test plots) and SG was unable to properly test their intermediate Level B technology, it is too soon to draw any broad generalizations about the overall effort. The program design, based on the sequential introduction of more expensive (and more risky) technologies in this zone of relatively poor farmers, has substantial merit. Farmers gained experience in the SG approach the first year using the very low-risk Level A package–they were extremely satisfied with the results. The rapid jump up to Level C technology appears problematic given our analysis of financial returns, BUT farmers remain enthusiastic about the higher yields obtained. The next few years of the program will be critical as SG searches for some combination of NRM practices and inorganic fertilizers that can be financially sustainable over time.

3.4. Lessons Learned from the Case Studies

A first lesson drawn from the two studies is that both SG and OHVN/NRM managed to get farmers engaged by focusing their initial extension efforts on alleviating a problem identified by farmers themselves: erosion for the OHVN farmers and plant disease for SG farmers. Although the costs (in terms of labor, community organization, and equipment needed) for the anti-erosion work were generally higher than those for the Apron+ seed treatment, both solutions were low cost enough to build a critical mass of early adopters who provided a demonstration effect for the spread of the practices to other farmers. These observations confirm the findings of many others–adoption is stronger if farmers are directly involved in identifying problems.

A second lesson is that an extension program with a long list of à la carte options from which farmers can select improvements that best meet their resources, problems, and willingness to bare risk is more likely to maintain farmer interest and high levels of participation than a program with a limited number of options. SG, for example, has a relatively short list of technical options and has not yet identified a sufficiently profitable combination of follow-up technologies to introduce after getting farmers engaged with the short-cycle seed and fungicide. The very long list of practices offered by OHVN has encouraged farmers to make adoption and improvement a way of life rather than a special event associated with a short-lived project.

A third lesson is that the demonstration effect of test and control plots can be an extremely powerful extension tool when used well. SG test plots are to be commended as a particularly good way of demonstrating to both the participant farmer and non-participants the yield differences attributable to the new technology. OHVN has no formal program for comparing yields of different practices and not all OHVN/NRM practices lend themselves to this type of comparative method; nevertheless, the yield impacts of some of the OHVN recommendations could be better appreciated using this type of demonstration approach.[7]

A fourth lesson is that test and control plots need to be used to demonstrate not only the yield differences but also the differences in net returns to the technologies being compared; focusing on yield differences without paying adequate attention to farmer training in basic financial analysis of alternative technologies can lead to major credit reimbursement problems.

A fifth lesson is that basic literacy and management training make a tremendous difference in farmers ability to manage new technologies on both an individual and a community level. OHVN farmers having received CLUSA training were much more in charge of their farms and their communities than OHVN and SG farmers not having benefitted from comparable training.

A sixth lesson is that the adoption of both NRM practices and external inputs is facilitated by the presence of a cash crop in the cropping system. SG introduced fertilizer to Segou farmers before promoting NRM practices. This is similar to what OHVN did before the creation of the NRM program, BUT the key difference is the nature of the output markets for the crops concerned. Millet is a semi-subsistence crop with poor marketing prospects and cotton is a cash crop with a guaranteed market and relatively stable producer price. Under current market conditions in Mali, it remains questionable whether there can be an adequate incentive for any type of agricultural intensification in the millet/sorghum production systems of the Segou Region if there is no viable commercial crop. This problem needs to be addressed by research to identify new crops as well as by developing markets for existing crops (e.g., through processing or animal feed industries and responding to regional rather than only national demand).

A seventh lesson is that NRM as well as external inputs tend to be adopted by better off farmers first. One expects external inputs to go to the wealthier farmers given the costs, but it is often thought that NRM is a better way to go for poor farmers. For most farmers, building anti-erosion barriers means having access to carts and draft animals; even when barriers are built with community efforts farmers able to provide the equipment will be among the first to benefit. Farmers wanting to use improved manure can make small advances by digging manure and compost pits, but only the farmers who can afford to own many animals are able to move up to permanently stabled livestock practices that provide important quantities of improved manure.

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[7]For example, many farmers are not adding crop residues to the manure being collected from stabled animals although research results show that the yield impact of adding theses residues is important. Two plots grown side by side with and without the crop residues might be a way of demonstrating that the extra effort is worth the investment.

4. Moving Ahead

SSA has an historic opportunity to reverse the current trends of stagnant productivity and declining soil fertility. The challenge is to begin the process of moving SSA from the low point of the soil degradation curve to levels which are close to pre-disturbance (native) fertility. Effectively, this means that long-term fallows, which accomplished this task in the past, need to be replaced by (or adapted to) appropriately integrated systems that include fertilizers or other effective input sources, no-till (or mulch tillage), cover crops, rotations, and/or agroforestry practices based on sound agro-ecological principles. That is, systems that take advantage of natural restorative processes and are, therefore, efficient in terms of fertilizer and water requirements as well as costs and labor. This is especially critical for smallholder farmers who make up the vast majority of agricultural producers in SSA and are faced with severe economic and technical constraints (Weight and Kelly, 1999).

Case study evidence presented suggests that OHVN and SG have made some important steps in promoting adoption of these types of practices. We find the most progress among farmers who:

(1) have benefitted from excellent literacy and management training,
(2) have benefitted from extension services that rely on demonstration plots and training methods that combine both individual and community approaches to improved crop management
(3) can chose technologies from a broad, à la carte menu, and
(4) produce a cash crop with relatively stable output prices and input access

In addition, there is strong evidence that supporting services that contribute to both input and output market development (policy reform, transport and communications infrastructure, market information systems) can stimulate adoption and sustained use of improved technologies in zones where farmers produce a commercial crop.

A major challenge remains in promoting adoption of technologies to improve soil fertility in zones where farmers do not produce a commercial crop. Given the important role that cash crops play in stimulating adoption (Reardon et al. 1996, Strasberg et al., 1999, and Govereh and Jayne, 1999 among others) we find ourselves asking if SG–whose mission is to deal exclusively with food crops-- shouldn't reconsider the zones in which it intervenes or its philosophy of working only with food crops. Would SG be in a better position to foster the use of improved technologies on food crops if it were working in a area that already had a cash crop?

For the OHVN, we ask if they could benefit from collaboration with SG in an effort to further intensify cereal production. The NRM practices promoted by OHVN have improved cereal yields to some extent, but the aggregate yields are still relatively low. What fertilization technologies can be promoted for farmers who do not have the resources to permanently stable their livestock? What should be recommended for farmers who have gotten yields consistently up above 1 ton/ha but want to aim for yields of 1.5 - 2 tons? These appear to be issues that a collaborative SG/OHVN effort would be well placed to resolve given the complementary approaches and firm evidence from the scientific literature concerning NRM/external input complementarities.

Specific suggestions for moving forward in Mali and elsewhere include:

⇨Increase coordination of different soil fertility programs in an effort to maximize potential complementarities of NRM and Green Revoloution type approaches.

⇨Focus on *extension* of NRM/fertilizer technologies where they are most likely to succeed (e.g., where there are commercial crops) while focusing on *research* to improve markets and identify more appropriate crops and technologies for areas where there are currently no promising commercial crops.

⇨Combine agricultural extension with high quality literacy and management training provided by specialists in these areas.

⇨Conduct more financial analysis of on farm demonstration plots
- ➜Train farmers to do analyses and include them in discussions of results
- ➜Reconcile differences between farmers' and economists' perspectives
- ➜Make sure that time and risk dimensions are taken into account

⇨Improve monitoring of the impacts of NRM and fertilizer adoption on aggregate yields, GDP, soil quality, etc.

TABLES

Table 1. Physical Indicators of NRM Adoption

	Level of Adoption (units)				
NRM themes	Prior to 1997	1997-98	1998-99	1999-2000	Sum
Rock lines (m)	79400	6485	10076	6581	102543
Branch barriers (m)	18500	780	2011	2333	23624
Small dikes (m)	38900	1492	775	457	41624
Vegetative bands (m^2)	8998	1341	4000	5653	19969
Living fences (m)	127022	12000	11831	12893	163746
Permanent field markers (ha)	1098	599	846	799	3322
Protected areas (ha)	450	450	615	750	2265
Diversionary gullies (n)	1417	625	1171	100	3313
Fire breaks(m)	5250	1406	615	500	7771
Controlled land clearing (ha)	140	300	-	-	440
Village managed forests (n)	1620	35	-	-	1655
Wells (n)	120	13	13	9	155
Deeping of mares (n)	68	2	1	2	73
Improved bas-fond (ha)	20	-	-	-	20
Village tree nurseries (n)	57	15	5	28	105
Plants from tree nurseries (n)	178800	13318	14640	45576	252334
Village woodlots	447	23	19	18	507
Improved cooking stoves (n)	2340	745	312	631	4028
Manure pits (n)	2268	265	338	-	2871
Stables for collecting manure (n)	13608	140	135	-	13883
Permanently stabled livestock (n)	146	8	-	-	154
Compost pit (n)	1303	399	490	50	2242

Source: OHVN December 1999 report and other OHVN survey data . Notes: m=meters, n=number.

Farmers, Recovered Hectares, and Settled Farms

Sector	Villages	Farms	Recovered Area (ha)	Settled Farms
Kangaba	53	1529	3027	296
Bancoumana	57	2335	3221	234
Ouélessébougou	97	3628	7604	1054
Dangassa	33	534	434	180
Fouani	110	3295	7264	600
Kati	70	1787	1303	241
Faladié	35	951	2274	275
Koulikoro	73	1358	2075	449
Sirakorola	79	2220	7656	552
Percent coverage	60	47	17	--

Source: OHVN 1999 survey data.

Table 3. Area, Production and Yield Data for the OHVN: 1991/92 - 1998/99

		1991	1992	1993	1994	1995	1996	1997	1998	Trend
Cotton	area (ha)	10506	12201	8624	11692	14605	23158	30750	35816	+
	prod (tons)	11842	12494	10684	13097	16167	21990	28927	33740	+
	yield (hg/ha)	1127	1024	1239	1120	1107	950	941	942	-
Millet	area (ha)	30906	31516	31892	34188	36660	35732	38149	37422	+
	prod (tons)	30226	23900	26700	31800	32441	36095	38714	35595	+
	yield (hg/ha)	978	758	837	930	885	1010	1015	951	stagnant
Sorghum	area (ha)	46603	48334	48140	51213	56009	59431	66390	72572	+
	prod (tons)	50508	43911	44622	47904	50292	64638	73047	75901	+
	yield (hg/ha)	1084	908	927	935	898	1088	1100	1046	stagnant
Maize	area (ha)	11099	11485	11648	12157	12834	13072	14411	15457	+
	prod (tons)	13845	13110	13938	11214	12929	14594	16814	20033	+
	yield (hg/ha)	1247	1141	1197	922	1007	1116	1167	1296	stagnant

Source: OHVN, Septième Session du Conseil d'Administration, Plan de Campagne 1999-2000, pg. 16.

Table 4. Case Studies Illustrating NRM yield increasing results over time (kg/ha)*

	First Year	Current Year	Total Years	Average Yield	Average Change/year	Average of case studies	Zone average 1991-1998
Millet						1064	921
Amadou Bagayoko/Ouéles	685	1325	6	1039	128		
Masiamé Coulibaly/Gouani	800	1300	8	990	71		
Drisa Bakayoko/Gouani	750	1600	5	1032	212		
Daouda FombaGouani	980	1340	5	1170	90		
M. Coulibaly/Sanambele	600	1145	6	921	109		
Traoré/Dafara	1100	1350	6	1230	50		
Sorghum						1170	998
Amadou Bagayoko/Ouéles	638	1250	6	983	122		
Masiamé Coulibaly/Gouani	950	1850	9	1452	225		
Drisa Bakayoko/Gouani	930	1430	5	1162	125		
Daouda Fomba/Gouani	1000	1380	5	1236	95		
M. Coulibaly/Sanambele	1000	1250	6	1082	50		
Traoré/Dafara	1000	1250	6	1105	50		
Maize						1469	1137
Amadou Bagayoko/Ouéles	950	1500	6	1303	110		
Masiamé Coulibaly/Gouani	1250	3200	9	1742	244		
Drisa Bakayoko/Gouani	1050	1900	5	1360	212		
Daouda Fomba/Gouani	1200	1800	5	1472	150		
Cotton						1327	1056
Amadou Bagayoko/Ouéles	700	1330	6	1058	126		
Masiamé Coulibaly/Gouani	1410	1410	9	1588	0		
Drisa Bakayoko/Gouani	1400	1232	5	1470	-42		
Daouda Fomba/Gouani	1030	1040	5	1388	2		
M. Coulibaly/Sanambele	950	1022	6	1121	14		
Traoré/Dafara	890	1164	6	1339	55		

*Practices used: rock lines, vegetative bands, contour plowing, 'grattage à sec', manure, fixed plots, end of season plowing.

Source: Farmer/OHVN records.

Table 5. Present value of gross income increasing potential of NRM during 9 years (FCFA)

Price scenarios (FCFA/kg)

Farmer: Masiamé Coulibaly

Low	Millet	70	Cotton	130
High	Millet	90	Cotton	150

Gross income from NRM (value of production with-value of production w/o)

	1990/1	1991/2	1992/3	1993/4	1994/5	1995/6	l996/7	1997/8	1998/9	**9-year Totals**	**Annual Averages**
Millet		14940	20880	22230	41580	na	50940	54450	55710	260730	37247
Cotton		28095	-59500	195470	40761	46378	140326	146062	45738	583329	72916
NRM income increases for Rotation A : Millet in 90/91, cotton in 91/92, etc.											
	0	28095	20880	195470	41580	46378	50940	146062	55710	585114	137823
NRM income increases for Rotation B : Cotton in 90/91, millet in 91/92, etc.											
	0	14940	-59500	22230	40761	46378	140326	54450	45738	305323	66157

	High Prices	**Low Prices**
PV Rotation A*	**34231 7 fcfa/ha**	**288562 fcfa/ha**
PV Rotation B	**15112 4 fcfa/ha**	**126269 fcfa/ha**

Notes: Farmer didn't produce millet in 1995 so cotton income substituted in rotation B

*Discount rate is 10%

Source: Farmer/OHVN records.

Table 6.Yields and Benefits of SG Technologies Tested on 1/4 hectare plots

	Level A Package	Level C Package
Cases	40	26
Avg. yield increase	133	138
Avg. value of increased production (FCFA)	10640	11031
Avg. supplemental cost for test plot (FCFA)	1025	7173
Net benefit (FCFA)	9615	3858
Value/Cost ratio	10	1.5

Source: INSAH/MSU/SG 1999 survey data, Segou Region.
Notes:
(1) US$1.00 = 600 FCFA;
(2) Millet price is 80 F/kg (1998/99 mean in the study zone).
(3) Level C package costs is 8150 fcfa; average supplemental costs are slightly less because we made adjustments for cases where farmers used extra seed or Apron+ on their control plots.

REFERENCES CITED

Bationo, A., and A.U. Mokwunye. 1991. Role of Manures and Crop Residues in Alleviating Soil Fertility Constraints to Crop Production: With Special Reference to the Sahelian and Sudanian Zones of West Africa. In A.U. Mokwunye (Ed.), Alleviating Soil Fertility Constraints to Increased Crop Production in West Africa, Kluwer Academic Publishers, Dordrecht.

Bekunda, M. A., A. Bationo, and H. Ssali. 1997. Soil Fertility Management in Africa: A Review of Selected Research Trials. In R. Buresh, P. Sanchez, and F. Calhoun (Eds.) Replenishing Soil Fertility in Africa, Soil Science Society of America (SSSA) Special Publication No. 51, American Society of Agronomy and Soil Science Society of America, Madison, WI.

Breman, H. and K. Sissoko (Ed.). 1998. L'intensification Agricole au Sahel.Karthala, Paris.

Easterbrook,G.1997. Forgotten Benefactor of Humanity. The Atlantic Monthly, January, 75-82.

Giller, K. E., G. Cadisch, C. Ehaliotis, E. Adams, W. D. Sakala, and P. L. Mafongoya. 1997. Building Soil Nitrogen Capital in Africa. In R. Buresh, P. Sanchez, and F. Calhoun (Eds.) Replenishing Soil Fertility in Africa, SSSA Special Publication No. 51. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Govereh, J. and T. Jayne. 1999. Effects of Cash Crop Production of Food Crop Productivity in Zimbabwe: Synergies or Trade-offs? MSU International Development Working Paper No. 74. Department of Agricultural Economics, Michigan State University, E. Lansing, MI.

Henao, J.; J. Brink, B. Coulibaly and A. Traoré. 1992. Fertilizer Policy Research Program for Tropical Africa: Agronomic Potential of Fertilizer Use in Mali. International Fertilizer Development Center and Institut d'Economie Rurale, Muscle Shoals, ALA and Bamako.

Howard, J., J. Jeje, D. Tschirley, P. Strasberg, E. Crawford and M. Weber. 1998. What Makes Agricultural Intensification Profitable for Mozambican Smallholders? An Appraisal of the Inputs Subsector and the 1996/97 DNER/SG2000 Program. MSU International Development Working Paper No. 69. Department of Agricultural Economics, Michigan State University, East Lansing.

Howard, J., Mulat Demeke, V. Kelly, M. Maredia, and J. Stepanek. 1999. Green Revolution Technology Takes Root in Africa: The Promise and Challenge of the Ministry of Agriculture/SG2000 Experiment with Improved Cereals Technology in Ethiopia. MSU International Development Working Paper No. 76. Department of Agricultural Economics, Michigan State University, East Lansing.

Jiggens,J. C. Reijntjes and C. Lightfoot 1996. Mobilising Science and Technology to Get Agriculture Moving in Africa: A Response to Borlaug and Dowswell, Development Policy Review, 14:89-103.

Nubukpo, Kako; Valerie Kelly, Mbaye Yade, and Marcel Galiba. October 1999. Accelerating Agricultural Intensification in the Riskier Environments of Sub-Saharan Africa. Select Paper accepted for the International Association of Agricultural Economists meetings, August 2000, Berlin.

OHVN. 1999. Septième Session du Conseil d'Administration, Plan de Campagne 1999-2000, Bamko.

Penning de Vries, F.W.T., and M.A. Djiteye (ed.). 1991. La productivite des paturages saheliens: Une etude des sols, des vegetations et de l'exploitation de cette resource naturelle. Pudoc, Wageningen.

Pieri, C. 1992. Fertility of Soils: A Future for Farming in the West African Savannah. Springer-Verlag, Berlin. Note: This is essentially the English translation of Pieri's 1989 publication *Fertilité ds terres de savanes*.

van de Pol, F. 1990. L''epuisement des terres, une source de revenus pour les paysans du Mali-Sud. Montpellier: Actes des Rencontres internationales Savanes d'Afrique, terres fertilies? 10-14 December 1990.

van der Pol, F. and B. Traoré. 1993. Soil Nutrient Depletion by Agricultural Production in Southern Mali. Fertilizer Research 36, 79-90. Kluwer Academic Publishers, Dordrecht.

Quinones, Marco A., Norman E. Borlaug, and Christopher R. Dowswell. 1997. A Fertilizer-Based Green Revolution for Africa. In R. Buresh, P. Sanchez, and F. Calhoun (Eds.) Replenishing Soil Fertility in Africa, SSSA Special Publication No. 51. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Reardon, T., V. Kelly, E. Crawford, T. Jayne, K. Savadogo, and D. Clay. 1996 . Determinants of Farm Productivity in Africa: A Synthesis of Four Case Studies. MSU International Development Paper No. 22. Department of Agricultural Economics, Michigan State University, E. Lansing, MI.

Reardon, Thomas. 1997. African Agriculture: Productivity and Sustainability Issues. In C. Eicher and J. Staatz (Eds.), Agricultural Development in the Third World, Third Edition. Johns Hopkins University Press, Baltimore.

Sanchez, P. A., K. D. Shepherd, M. J. Soule, F. M. Place, R. J. Buresh, A-M. N. Izac, A.U. Mokwunye, F. R. Kwesiga, C. G. Ndiritu, and P. L. Woomer. 1997. Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital. In R. Buresh, P. Sanchez, and F. Calhoun (Eds.), Replenishing Soil Fertility in Africa, SSSA Special Publication No. 51, American Society of Agronomy and Soil Science Society of America, Madison, WI.

Strasberg, P.; T. Jayne, T. Yamano, J. Nyoro, D. Karanja, and J. Strauss. 1999. Effects of Agricultural Commercialization on Food Crop Input Use and Productivity in Kenya. MSU International Development Working Paper No. 71. Department of Agricultural Economics, Michigan State University, E. Lansing, MI.

Swift, M.J. 1996. Sustainable Management of the Soil Resource: Developing a Framework for Research and Development. The World Bank, Washington, D.C.

Tefft, J. 2000. The White Revolution in R. J. Bingen, D. Robinson and J. M. Staatz (Eds.) in Democracy and Development in Mali. Michigan State University Press, E. Lansing, MI.

Wallace, M. B. 1997. Fertilizer Use and Environmental Impacts – Positive and Negative: A Review with Emphasis Upon Inorganic Fertilizers in Africa. Winrock International Institute for Agricultural Development, Washington, D.C..

Weight, D. and V. Kelly. 1999. Fertilizer Impacts on Soils and Crops of Sub-Saharan Africa.. MSU International Development Paper No. 21. East Lansing: Michigan State University.

Winrock International. 1997. An Assessment of Strategic Opportunities for Sustainable Agricultural Intensification in Sub-Saharan Africa. Report Commissioned by the Carter Center and USAID.

Yanggen, D., V. Kelly, T. Reardon, and A. Naseem. 1998. Incentives for Fertilizer Use in Sub-Saharan Africa: A Review of Empirical Evidence on Fertilizer Response and Profitability. MSU International Development Working Paper No. 70. Department of Agricultural Economics, Michigan State University, E. Lansing, MI.