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CEREAL TECHNOLOGY DEVELOPMENT— WEST AFRICAN SEMI-ARID TROPICS: A FARMING SYSTEMS PERSPECTIVE

End of Project Report
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In 1979, Purdue University implemented the Farming Systems Unit/Semi-Arid Food Grain Research and Development (FSU/SAGRAD) Project, headquartered in Ouagadougou, Burkina Faso. The project continued until June 30, 1986.

This end-of-project report covers major aspects of the farming systems research activities which took place.

The body of the report is substantive in that it presents major findings of this collaborative research effort in terms of:

(a) farming systems methodology in the West African Semi-Arid Tropics (WASAT);

(b) production constraints of existing WASAT farming systems;

(c) technology development of increased cereal production in that region; and

(d) policy implications and future avenues for research and extension.

We chose to structure the end-of-project report in this fashion for a specific reason. This was to make available in one place the more important and relevant methodological and empirical findings associated with accelerated agricultural development in that region.

The administrative report for the FSU/SAFGRAD Project (AFR-C-1472) is provided in the Appendices, along with a list of publications generated by FSU research.

Broader coverage and details of the scientific output of this activity are available in the thirty-six research reports and workshop proceedings associated with the FSU/SAFGRAD Project.

A life-of-project fiscal report has been submitted to the Agency for International Development under separate cover.

We trust that the efforts of Professors Nagy, Sanders and Ohm in developing this final report will be useful to all who continue this work.

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A FARMING SYSTEMS PERSPECTIVE

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
CIAT	Centro Internacional de Agricultura Tropical
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
FCFA	Franc Communauté Financière Africaine
FSR	Farming Systems Research
FSSP	Farming Systems Support Project
FSU	Purdue University/SAFGRAD Farming Systems Unit
IARC	International Agricultural Research Center
IBRAZ	Institut Burkinabè de Recherches Agronomiques et Zootechniques
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IITA	International Institute of Tropical Agriculture
ILRAD	International Livestock Research and Development Program
INTSORMIL	International Sorghum/Millet Program
IPIA	International Programs in Agriculture (Purdue University)
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières
IRRI	International Rice Research Center
MRT	Mechanical Ridge Tier
NARC	National Agriculture Research Center
OAU	Organization of African Unity
PCV	Peace Corps Volunteer
SAFGRAD	Semi-Arid Food Grain Research and Development Program
USAID	United States Agency for International Development
WASAT	West African Semi-Arid Tropics

CHAPTER I

INTRODUCTION

Food production and consumption trends in the Third World over the past two decades have shifted world attention from Asia to Sub-Saharan Africa (Paulino and Mellor, 1984). The Green Revolution in Asia--the increase in rice and wheat yields brought about by improved varieties and an expanded use of fertilizer and other purchased inputs--has greatly increased Asian per capita food production (Pinstrup-Andersen and Hazell, 1985). A similar Green Revolution phenomenon, however, has not yet taken place in sub-Saharan Africa. One of the areas of most concern in Sub-Saharan Africa is the geographical region of the West African semi-arid tropics (WASAT). Current food production and population growth trends have led many to adopt a Malthusian perspective about the future of the WASAT.

The countries of the WASAT include Senegal, Gambia, Burkina Faso, the southern portions of Mauritania, Mali, Niger, and Chad, and the northern portions of Ghana, Benin, Nigeria, and Cameroon (Norman, et al., 1981). Troll (1966) defines semi-arid tropics as regions where precipitation exceeds potential evapotranspiration for 2 to 7 months of the year. Figure 1 delineates the principal climatic zones in the WASAT based on annual rainfall levels (0.9 probability isohyets of 1931-60 rainfall data).[1]

The WASAT is one of the poorest regions in the world with 1984 per capita yearly incomes for countries in the area ranging between $US 80 and $US 300 (McNamara, 1985). The region as a whole has balance of trade and balance of payments problems. The economies depend heavily on foreign aid, borrowing, and worker remittances. People (labor) are one of the biggest exports from the region--an estimated 25% of the labor force of Burkina Faso works in neighboring non-WASAT areas (World Bank, 1981). The region exhibits a bottom-heavy age pyramid with country population growth rates ranging between 2.5% to 3.0% per year and a fertility rate averaging 6.5 children per adult female. The growth in per capita food production (1971-1984) for the region as a whole is negative while levels of food imports (largely from donor agencies) have increased dramatically over the last 25 years (McNamara, 1985; Paulino and Mellor, 1984).

The declining food production per capita is associated with the continuing droughts of the 1968-73 and 1976-80 periods (Nicholson, 1982) and the most recent 1984 drought. Other factors such as inadequate economic incentives for farmers and the failure to adapt and adopt new agricultural technologies have also been cited as explanations for the failure of food production to accompany population growth.

(Adapted from World Bank, 1985.)

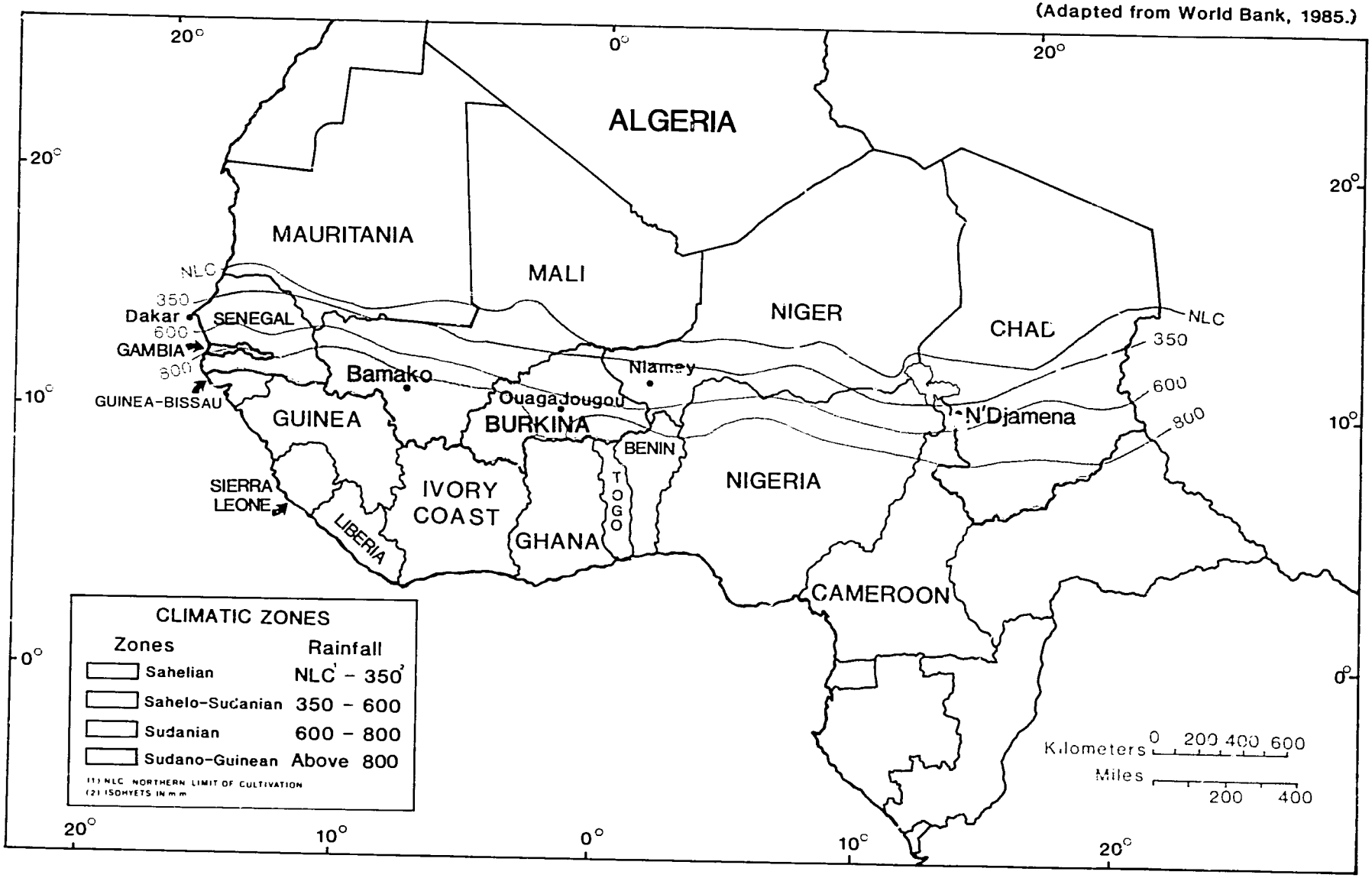


Figure 1 West African Sahelian and Sudanian Zones.

Since the WASAT does not have the man/land pressure of much of Asia and Asia has been successful in rapidly increasing agricultural production in its prime agricultural areas, it is useful to look at the resource base in this region. The present man/land ratios in the WASAT average roughly 15 persons per sq km (World Bank, 1985) compared with up to 600 persons per sq km in Asia (McNamara, 1985). The poorer agricultural resource base of the WASAT, however, cannot support the high man-land ratio of Asia (Matlon, 1985). For example, in the older settlement villages of the Central Plateau of Burkina Faso, man/land ratios are as high as 60 persons per sq km (World Bank, 1985). These high man/land ratios relative to the resource base have been causing the breakdown of the traditional bush-fallow farming systems. Traditionally, the crop area was cultivated for 3 to 5 years and then left idle for a decade or more to restore soil fertility. In many of the older settlement villages, increased population has meant limited access to new land, a shortening of the fallow rotation period and the cultivation of more marginal land (Norman, et al., 1982; Dugue, 1985). For example, in the village of Nedogo, Burkina Faso (Figure 2), many fields have been cultivated as long as the farmers can remember (FSU/SAFGRAD, 1983). Moreover, almost all the crop residues are utilized for feed or building materials, or else burned, further exhausting the fertility of the soil. Declining soil fertility in the older settled regions has been disrupting the cereal production systems, pushing the cereals into more marginal areas and encouraging a substitution of millet for sorghum (Ames, 1986).

During the high rainfall period of the fifties and early sixties intensive crop production was further extended into the Sahelo-Sudanian zone (World Bank, 1985). With the droughts and increased desertification of the late sixties and seventies many have become concerned with the possible interaction of human settlement and further desertification (Nicholson, 1982; World Bank, 1985). While this debate has not been resolved, there is no doubt that the resource base in much of the Sahelo-Sudanian zone has further deteriorated. The cereals deficit problem has become increasingly serious.

All three phenomena--the disappearing fallow system, the failure to incorporate crop residues, and the extension of crop cultivation into more marginal agricultural regions--lead to further soil deterioration in the absence of technological intervention. In overpopulated agricultural regions such as the Central Plateau of Burkina Faso, the bush fallow system is being replaced by a permanent cultivation system characterized by very low and stagnant cereal yields (Lang, et al., 1984; see Ruthenberg, 1980, for other examples of this dynamics).

Not all the WASAT is overpopulated. Rather, many of the regions can be characterized as frontier zones. For example, the eastern region of Burkina Faso (i.e., Diapangou, Figure 2) with man-land ratios of 15 persons

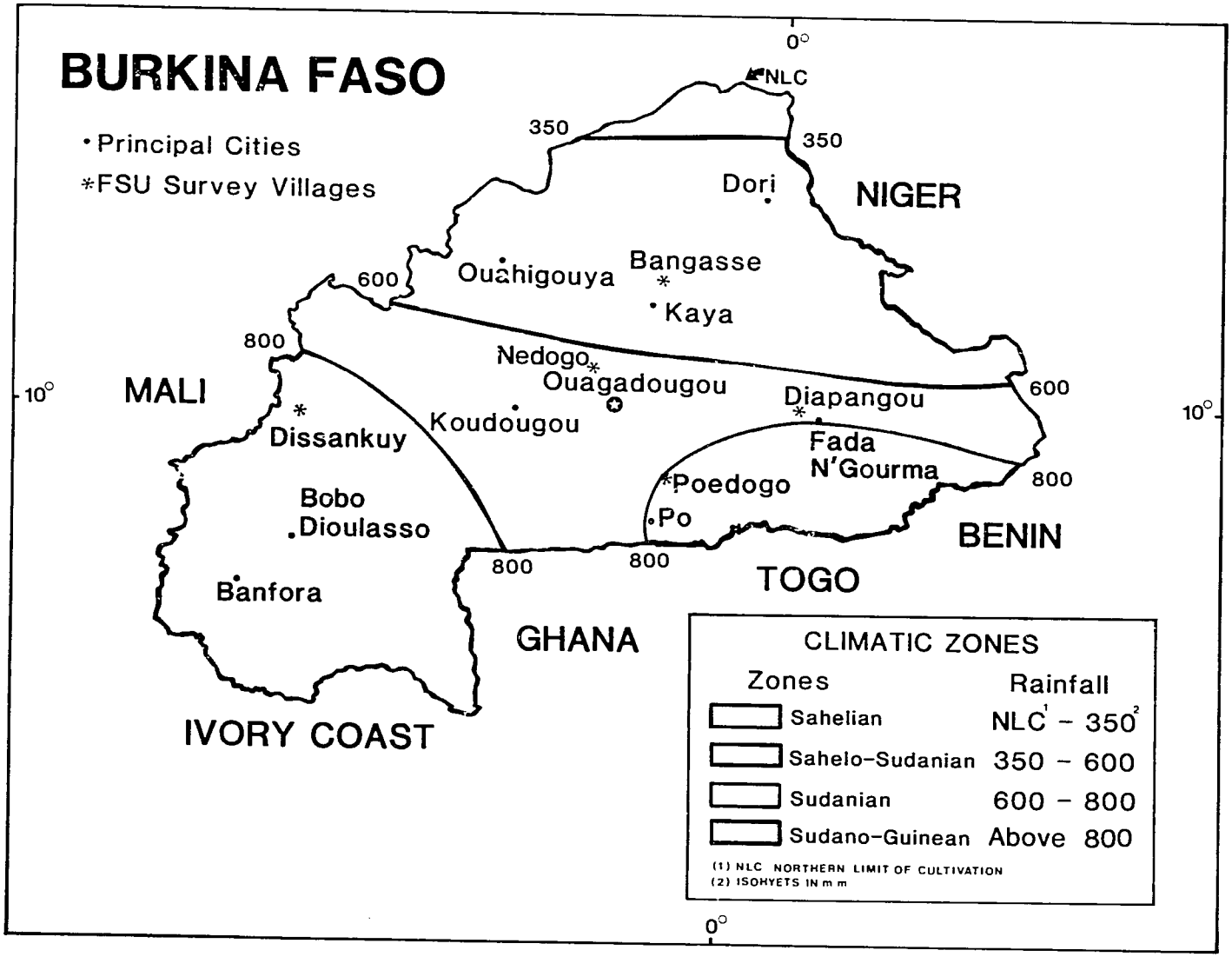


Figure 2 FSU research sites and climatic zones of Burkina Faso.

per sq km has surplus land and follows the bush-fallow system of cultivation. However, even on the frontier, as population pressure increases in the next five years, a phenomenon similar to what is now taking place on the Central Plateau of Burkina Faso would be expected to occur. It is becoming increasingly important to develop land substituting technologies for the overpopulated regions. And although labor substituting technologies are presently still very important on the frontier, at the present pace of development the frontier zones will confront similar problems to those in the overpopulated regions during the next decade.

Given the present cereals crisis in the WASAT it is becoming critical to develop or adapt new agricultural technologies which will reverse the Malthusian trends.[2] In the mid-sixties, before the start of the Green Revolution, similar Malthusian statements were made about the agricultural potential of the Indian sub-continent. However, during the late sixties and seventies agricultural regions in Asia with irrigation or regular, assured rainfall had the most rapid growth rates in technology diffusion ever empirically documented. Although the resource endowment in the WASAT is not as great as that of the Punjab and similar Asian regions, research reported here will attempt to show that there is substantial potential for cereal technology development in the WASAT.

The technology development process in the Purdue University/SAFGRAD Farming Systems Unit Project had two phases. The first phase was the development of a methodology to identify the pressing constraints to cereal production increase and the testing out on farmers' fields of technology alternatives available from the experiment station and from similar climatic regions in other countries. The second stage was the continued evaluation of successful technologies over a sufficiently long time period and in sufficient detail to allow researchers a feeling of reasonable confidence in their recommendations to both experiment station researchers and to the extension service and government officials involved in agricultural development. The principle chapters of this report (III and V) are concerned with these two phases of the technology development process. The basic methodological concepts potentially useful in other WASAT countries from the farming systems research in Burkina Faso are synthesized in Chapter III. In the technology evaluation of Chapter V the results of other WASAT agricultural researchers are combined with those of the Purdue University/SAFGRAD Farming Systems program to give a more comprehensive evaluation of the present state of cereal technology development in the WASAT. The conclusions synthesize the technology evaluation to draw out the implications for agricultural policy and for future extension and research.

Footnotes

[1] Rainfall averages have declined by 100 to 150 mm. per year since the mid 1960's. Updated isohyets using 1961-1985 data were not available. In depth information on the countries and regions of the WASAT can be obtained from Kowal and Kassam, 1978; McNamara, 1985; Norman, et al., 1981, and World Bank, 1985.

[2] At present, there is some scope for migration to lower population density areas with better soils and rainfall within the WASAT since health investments have been made to eradicate river blindness in some of the more fertile valleys (Sanders, et al., 1986). Several relocation programs have already been undertaken in Burkina Faso (McMillan, 1979). Relocation programs are costly and represent a short to intermediate solution for the WASAT. Also, people are reluctant to relocate and leave family, friends, and familar surroundings.

CHAPTER II

THE PURDUE SAFGRAD FARMING SYSTEMS UNIT

The Purdue University Farming Systems Unit (FSU), funded by the United States Agency for International Development (USAID), was part of the Semi-Arid Food Grain Research and Development Project (SAFGRAD) from December, 1978 to June, 1986. SAFGRAD is a regional research coordinating program implemented by the Coordination Office of the Scientific, Technical and Research Commission of the Organization of African Unity (OAU/STRC). The SAFGRAD project works in cooperation with 28 sub-Saharan member countries with the coordination office located in Ouagadougou, Burkina Faso. The principal objective of the SAFGRAD project is to coordinate and strengthen programs in the semi-arid regions of sub-Saharan Africa that are involved in improving sorghum, maize, millet, cowpea, and groundnut yields.

In the West African Semi-Arid Tropics (WASAT), SAFGRAD coordinates a research and pre-extension program. The regional on-station component research is headquartered at the Central Experiment Station at Kamboinse in Burkina Faso and undertaken by IITA and ICRISAT. Another component of SAFGRAD in the WASAT is the Accelerated Crops Production Officers (ACPO) program, which conducts regional pre-extension and demonstration trials. An integral part of the overall program is the farming systems unit which provides linkages between on-station research and the ACPO/extension programs. The research and extension personnel of SAFGRAD (including the FSR unit) meet yearly to submit an annual report to a Technical Advisory Committee (TAC). The TAC reviews the research programs and submits the results and recommendations to the Consultative Committee (CC), which is a management and policy committee for SAFGRAD. The results are passed on to host country research and extension institutions.

Within the SAFGRAD framework, farming systems research for Burkina Faso was provided by Purdue University for seven years up to June 1986. In the seventies, farming systems methodology was still in its infancy. Its mandate included the development of methodological guidelines that could be implemented in host country national and SAFGRAD sponsored farming systems programs. The specific objectives of FSU were as follows:

1. to identify the principle constraints to increased food production,

2. to identify technologies appropriate for farmers which could overcome the production constraints,

3. to develop and implement a multidisciplinary research method which could guide production technology and production research to directly address these production constraints,

4. to identify the elements of that method which could be implemented in national farming systems research programs, and

5. to train host country personnel to assume increasing responsibility in their contribution to research.

During the life of the FSU program, agronomic and socio-economic research was conducted at the on-farm level in five villages (Figure 2). The specific operational procedures and evolution of the FSU program are reported in Nagy, et al., 1986b. The agronomic and socio-economic field campaign findings of the FSU program are presented in FSU Annual Reports and other FSU publications.

In the final year of the contract, the FSU program completed the transfer of its in-country staff and program to the national agricultural research institution of Burkina Faso (IBRAZ). FSU also worked with the IFAD supported SAFGRAD farming systems personnel who backstop the national farming systems programs in Burkina Faso and Benin. Through regional symposia and consultation, the methodology and results were made available to other SAFGRAD countries as well. Details of the program transfer and field staff training component of objective 5 are reported in the 1985 FSU Annual Report (Nagy and Ohm, 1986).

CHAPTER III

FARMING SYSTEMS METHODOLOGY IN THE WEST AFRICAN SEMI-ARID TROPICS (WASAT)

Introduction

The basic concept of farming systems research is that the research system could function more efficiently if more information on the constraints which prevent farmers from improving their well-being was obtained at an earlier stage of the research development process than is common in the developing countries. Farm-level constraints can be identified with both surveys and on-farm trials. A further extension is to supplement the on-farm trials with whole-farm modeling. This chapter will be concerned with all three approaches.

In developed countries the two-way linkages of communication between farmers and agricultural scientists function better than in the WASAT due to higher educational levels of the farmers, better agricultural information systems, and financial mechanisms in developed countries which reward the agricultural research establishments and individual scientists for their contributions to resolving farm-level production problems. Farming systems research can provide an alternative communication linkage which does not require advancements in general education or major changes in the institutional orientation of national research systems.

The clientele of Farming Systems Research will depend upon the institutional setting and the stage of development of the technology. In the initial phases of the agricultural development process, as in the WASAT, the most important directional flow of information is to the researchers,[1] for several reasons. First, farming systems, even in low input agriculture, are very complex with many systems interactions. Farmers have multiple objectives and constraints and these can vary in importance and evolve over time and even in response to the conditions of the production season (Norman, 1982).

Agricultural scientists in developing countries often underinvest in understanding these complex systems and farmers' objectives before beginning research. Further, they may not adequately respond to knowledge which is available. When farmers do not adopt the technologies produced on the experiment station and recommended to them, the initial reaction of agricultural scientists in developing countries is often that the problem of non-adoption is with the farmers, the extension service, or national economic policies, rather than with the technologies themselves.

Technology development requires a thorough understanding of the scientific concepts applied on the experiment station plus a multi-disciplinary approach to understanding the complexity of the farmers' environment, farming systems, and decision-making process. The most fundamental difference between the experiment station and farmers' fields is the necessary shift

from component parts of new technologies, as produced on the experiment station, to systems with important interactions such as are characteristic of farmers' production systems.[2]

Farming Systems Research helps to overcome these differences by enabling agricultural scientists to improve their understanding of the complexity of the farmers' systems and thereby become more efficient at identifying and resolving the research problems involved in overcoming farmers' constraints. Two desired final products are a more efficient agricultural research system and an increase in mutual comprehension between farmers and researchers. Another product is the facilitation of adoption of new systems of agricultural technology so that these systems can be more rapidly incorporated into the testing and diffusion program of the extension service.

The principal stages in farming systems research can be identified by responding to the following questions:

a) What do you do first to describe the farmers' production systems? How much description is enough?

b) How do you plan and organize on-farm trials? When do you do it? What are the differences between experiment station and on-farm trials?

c) How do you analyze and supplement the data coming out of the on-farm trials? What are the relevant questions to be answered about new technology performance on farms?

d) At some point in technology development, outside factors (exogenous variables), such as economic policy or the further development of input production or distribution capacity such as a fertilizer marketing system, improved credit or a seed industry, may be constraining technology introduction. How does FSR set up its own boundaries while still maximizing its effectiveness in providing relevant information to facilitate the production of new technologies?

e) Who should do the farming systems research? Presently, International Agricultural Research Centers spend an estimated 10 to 15 million dollars annually on FSR (Anderson and Dillon, 1985, p. 1).

The following sections of the paper will attempt to address these specific questions on farming systems methodology. Clearly, there will be some biases from the experiences of the Farming Systems Unit in Burkina Faso and the other FSR experiences of the authors. These experiences will be utilized as illustrations.

Describing Farmers' Environments, Production Systems and Objectives: The Baseline Study Stage

If the principal objective of farming systems research is to improve the understanding of agricultural scientists about farm-level conditions, then this data-collection or description process must begin with them. They help to define the research problems and objectives of the fieldwork and to understand the particular target group of farmers. Agricultural scientists need to be involved in farm-level research design in order to provide more information and to evaluate the accuracy of their hypotheses about farmer conditions and decision-making.

The utilization of baseline studies for developing research priorities requires the identification and ranking of the principle constraints to increased output of the commodities studied. This is not a simple process since there will be a strong bias from the individual disciplines of the researchers in the definition of the farm-level constraints. Breeders will identify varietal characteristics for overcoming specific yield constraints; pathologists, diseases; economists will point out particular policies or markets which reduce the profitability of specific new technologies. Hence, a multi-disciplinary approach to the definition of constraints will be necessary from the beginning of the research design process. Some investment by researchers in the understanding of other disciplines will also be necessary.

Useful baseline research has included the economic quantification of production losses from various insects and diseases. This information helped confirm the research strategies of resistance breeding for field beans at CIAT (Sanders, 1984; Sanders and Lynam, 1982). Similarly, in Burkina Faso the initial anthropological descriptions of farming systems (M. Saunders, 1980) and the economic analysis of farmers' objectives and seasonal labor constraints helped provide orientation for agricultural researchers in the farm trials (Lang, et al., 1984).

An important issue within this baseline stage is that it is extremely easy to overinvest in data collection and descriptive surveys. Moreover, much of the literature on farming systems puts an excessive emphasis on baseline data collection so that the research problem identification, hypotheses, analytical methodologies, and even literature reviews are neglected. The frequent consequence is the amassing of large quantities of data, which are only partially analyzed. Even with analysis, much of the data collection traditionally undertaken at this stage of FSR has resulted in interesting descriptions of little relevance to researchers in redefining their research priorities.

There are several methods for avoiding the pitfalls of random and largely irrelevant data collection. The first is an extension of a method presently utilized by many agricultural scientists to identify for themselves the important constraints in farmers' fields. This involves their going into the field to see farm-level problems in their disciplinary

area.[3] A simple extension is to make these field trips multi-disciplinary and to involve some pre-trip discussion and mutual definition of field objectives. If farm-level interviewing remains unstructured, the data-amassing problem can be avoided. Multi-disciplinary collaboration is begun and can be continued in the development of a report synthesizing the field observations. Often these initial trips or "sondeos" have led to more formal multi-disciplinary questionnaire development and surveying in a second stage. Clearly, with the involvement of several disciplines, the demand for data can increase exponentially.

To more rapidly interest the agricultural scientists, a different technique is suggested. At any given time, agricultural scientists generally have their own ideas of what will work on farmers' fields. These ideas can come directly from their own experiments, from observations of farmers in other regions, or from the literature. The suggestion here is to move rapidly into on-farm trials.[4] This will then give a defined framework for supplementing on-farm trials with diagnostic surveys which have well-defined objectives, i.e., to better evaluate specific socio-economic issues involved in introducing these new technologies, tested on the farmers' fields, into the farmers' production system.

In these baseline surveys of the functioning of the farm and household systems at the beginning of an FSR project, the anthropologists and sociologists have often made outstanding contributions to our understanding (M. Saunders, 1980; Reeves and Frankenberger, 1982). When these surveys by the social scientists have been integrated with the research objectives of agricultural scientists, their utility has been further increased. It is recommended that a farming systems project begin with baseline surveys of farm and household conditions in each major target area, preferably undertaken by an anthropologist (also see Simmonds, 1984, p. 74). These baseline studies and a commencement of on-farm trials in the first production season are suggested as the appropriate way to begin farming systems research in the WASAT.

The principal emphasis here is on moving rapidly to on-farm trials with supplementary analysis to provide understanding of the potential role of the new technologies in the whole farm system. The methodology for this type of evaluation will be explained in detail in the fourth section on Evaluation. As this type of on-farm testing and modeling analysis is being undertaken, further diagnostic surveys are often useful to complement the principal investigation of the on-farm trials and farm modeling. An example in the Burkina Faso FSU program, after three to five years of on-farm testing in different villages, was a survey to evaluate adoption by participant and non-participant farmers of the new technologies tested.

Designing and Implementing On-Farm Trials

There are two central issues in the implementation of on-farm trials. First, multi-disciplinary collaboration is essential, especially between agricultural scientists and economists.[5] Secondly, the research objectives

of the experiment station and on-farm trials are different, hence the organization, design, and analysis of the on-farm trials are different from those on the experiment station.

True multi-disciplinary collaboration is not easy since each discipline has its body of literature, its journals, certain statistical methods customarily dominated by its practitioners, and even its philosophical attitudes about research and the process of agricultural development. Moreover, universities and many agricultural research institutions are organized by discipline. Promotions in universities are linked to publications in the high prestige journals of individual disciplines.

To overcome these barriers between disciplines, strong institutional support and continued personal relationships are both required. There is a tendency in farming systems projects to give control of the on-farm trials to either the biological or the social scientists or to compartmentalize their efforts. For example, the agricultural scientists might manage the researcher-managed on-farm trials and the economists the farmer-managed trials. Or the agricultural scientist might ask the economist's help in interpreting data without collaborating with him/her on field research planning and design.

The most basic differences between agricultural scientists and economists are in their treatment of data (Collinson, 1981, p. 442). Agricultural scientists are trained to be extremely careful in data generation, to verify results over a number of years, and to utilize variations of analysis of variance to analyze the significance of yield differences. However, policymakers generally need new technology recommendations in short time periods and farmers are more interested in the profitability and fit into their operations of one or two new systems of production than in the identification of the level of significance of the treatments and their interactions.

Economists, with simple modeling and synthetic estimates (judgements of agricultural scientists), can help fill the gap between the public policymakers' and the farmers' demands for new technology information and the output from agricultural scientists. Some knowledge of the agricultural sciences and some simple modeling are the necessary components of the economist's contribution. The primary requisite for successful interdisciplinary collaboration is the desire of the team to respond rapidly to real world problems of technology evaluation even if the data utilized are preliminary and some of them are synthetic. Preliminary results can always be refined and improved with further experiments and/or data collection and analysis.

One important contribution of Farming Systems Research has been to demonstrate the strategic importance of on-farm testing of new technologies as a critical component of the agricultural research process (for an estimate of the rate of return to this research see Martinez and Arauz, 1984). The primary unit in new technology production is the experiment station.

However, once the component parts of new technologies have been tested on the experiment station, they can be combined into packages and tested under a wide range of farming conditions (Figure 3). The synergistic or multiplicative (rather than additive) impact of combining several factors of production is well known in the agricultural sciences. The individual factors are identified and measured on the experiment station. In the on-farm trials, combinations of factors are evaluated to identify new systems of production that are profitable and fit into farmers' production systems.

On the experiment station, non-treatment inputs are held at fixed, but generally high, levels so that they do not affect the performance of the treatment input(s). Usually, the potential for static (increased variance) in the response of the treatment input(s) is reduced by the high levels of utilization of other inputs. Experiment station trials tend to study one or sometimes two factors in considerable detail. Experiment stations are usually selected in the best agricultural regions and over time, due to different cultural practices, the agricultural conditions become substantially different from those on farmers' fields[6] (Sanders and Lynam, 1982; Byerlee, Collinson, et al., 1981).

Once the more basic experiments have been undertaken on the station and before recommendations are made, farm-level testing is necessary. If the technology performance depends upon soil, climate, insect or disease incidence, the farm trials can help identify these factors and estimate the economic impact of overcoming the specific constraint at different levels of its incidence. For example, fertilizers will have a larger impact in low soil fertility regions and a disease resistant variety will be more impressive where the disease occurs. A water retention technique such as tied ridges would be expected to work better in the heavier soils. In sandier soils, the ridges will be more rapidly destroyed by wind or water. Moreover, the on-farm trials provide a crude estimate of the relative importance of the specific constraints on the farmers' fields during the production period evaluated.

One method for analyzing these between-farm differences in new technology performance in greater detail is to utilize a large number of farms for the farm-level trials. Repetitions are often made by increasing the number of farms rather than including repetitions on each farm site (DeDatta, et al., 1978; Sanders and Lynam, 1982). One implication of this design is that variance within farms cannot be separated. Another is that within any constrained planting season, a larger number of farms can be included.

Another way to handle the between-farm variation in technology performance is to stratify the environments in which the technology is evaluated.

Experiment Station	On-Farm Trials
More Basic Research	More Applied Research
Component Research	Systems or Package Research
Variance from Non-Treatment Factors Minimized	Analyze Variance from Non-Treatment Factors
Repetitions on Same Experiment	Replications Across Farms
New Technologies Originate Here Primary Activity	New Technologies Evaluated Here Secondary Activity

Emphasis on Feedback of Information to Researchers in the Experiment Station

←

Based Upon Technology Performance on Farms--Request Technology Modifications from the Experiment Station

→

To Extension Service for Further Testing and Dissemination

Figure 3. Stages of the research process.

SOURCE: Adapted from Sanders and Lynam, 1982, p. 99.

Soil types, rainfall regimes, or even farmer characteristics can be utilized to define research domains. However, the performance of many new technologies under different farm-level conditions is often a stochastic event. The incidence of diseases and insects is unknown at planting time, so there is no way to define research domains for these problems. If there is a large sample, the data can be stratified after the trials. Since it is often difficult in practice to minimize the on-farm performance variations of new technologies by defining research (or recommendation) domains with homogeneous characteristics, it is frequently necessary to employ larger sample sizes, i.e., more on-farm trials. The number of trials necessary will also depend upon the types of technologies evaluated.

In the initial years of on-farm testing (early and mid-'70s) economists and other social scientists frequently administered the trials. Over time, agricultural scientists have generally taken over the implementation of these trials. This transition has improved trial quality since agricultural scientists are trained for this activity. However, the failure to adequately specify the objectives of on-farm testing can lead to trials which are only replicas of experiment station trials.

With the above detailed examination of the on-farm methodologies, it is easy to forget that the origin of new technologies is the experiment station. This is the primary unit in the technology development process. The on-farm testing performs an important evaluation function in the research production process but it is secondary to the primary organ of agricultural research, the experiment station. Moreover, the quality of the on-farm trials will depend upon the input from the agricultural scientist. In the design and the evaluation phases, the interdisciplinary input especially from economists will be critical.

The integration of the on-farm and station-based research and their links to diagnostic surveys of the farmers in the target regions and to the operational research utilizing the data resulting from the on-farm trials are illustrated in Figure 4. As mentioned previously, both the diagnostic surveys and the evaluation of on-farm trials have important roles and should function simultaneously. The operational research for the evaluation of these on-farm trials will be considered in the next section.

Evaluation of On-Farm Technology Performance

The on-farm trials combine several factors or component parts, previously evaluated on the experiment station, into different systems or packages. Isolating each factor and its interactions in these trials frequently becomes unmanageable. Beets (1982) cites an IRRI cropping system experiment with 750 possible treatment combinations. However, the principal concern of the on-farm trials is to identify combinations[7] of factors, which are profitable and fit into the farmers' systems of production.

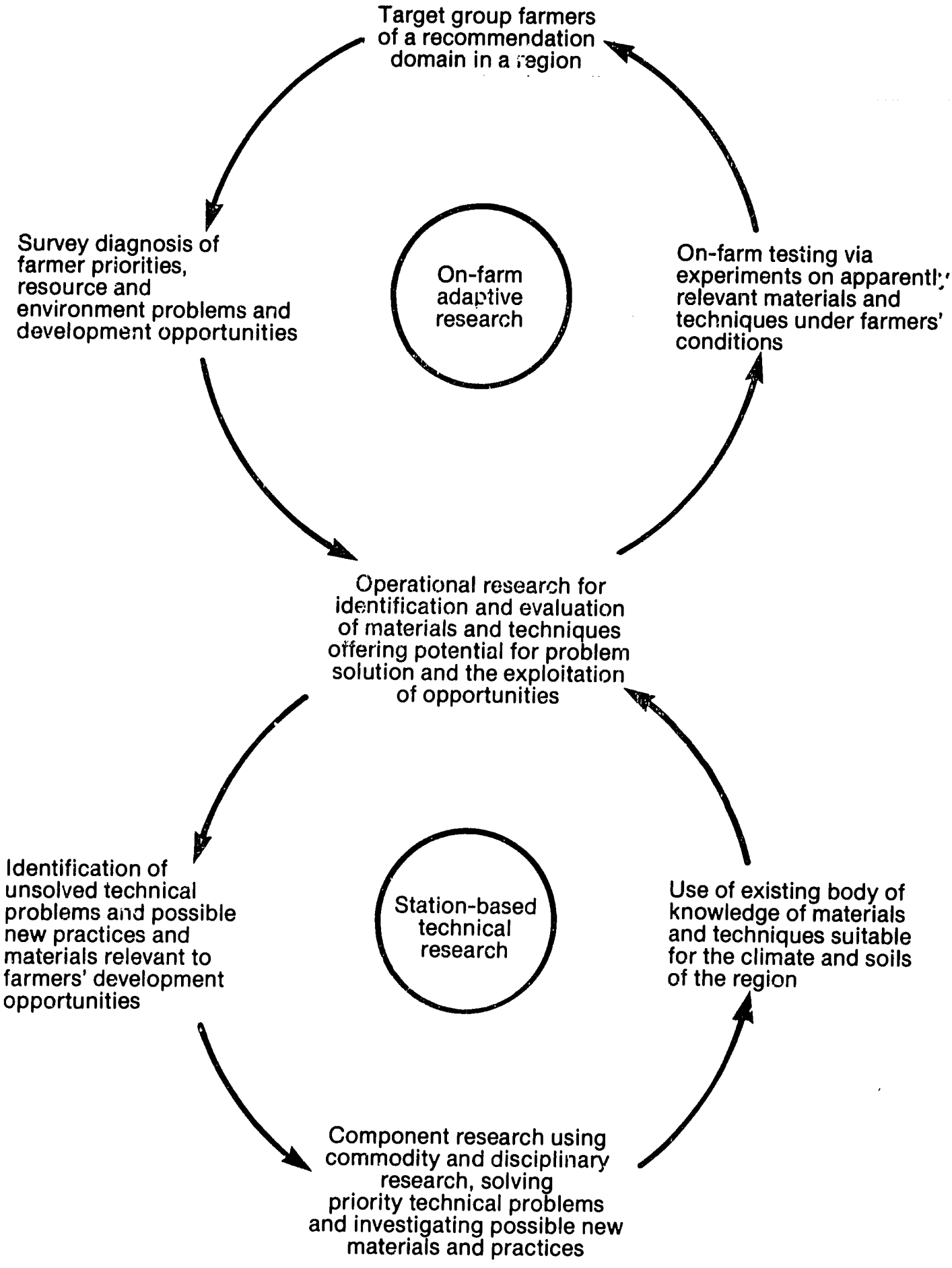


Figure 4. Schematic view of farming systems research method (after Collinson 1982).

The treatments of the on-farm trials representing different systems pass through three phases of evaluation (Figure 5). The first phase is identical to the experiment-station analysis, some variation of analysis of variance (ANOVA). It determines whether under farmers' conditions there are significant yield differences with the new technologies as compared with the treatment representing traditional farmers' practices.

However, technology needs to move beyond yield differences to be acceptable to farmers. With a minimal increase in data requirements from the local environment, the yield data from the treatments are converted into gross and then net revenue, utilizing product prices and input costs. This simple budgeting answers the second question in the flowchart of Figure 5: Is the new technology more profitable than farmers' traditional practices?

Mention should be made here of two frequently cited problems with simple budgeting: (a) price variation over time and within the production season, and (b) costing of non-traded inputs such as land and family labor. Product prices can vary substantially within a year, especially with the customary post-harvest price collapse, and between years in regions with substantial climatic fluctuations and limited governmental role in price stabilization. Moreover, input costs will depend upon government subsidies and the real input costs to the farmer will also depend upon the availability of an input, such as fertilizer, at the right place and the right time. Questions about the appropriate prices and costs to be utilized in the evaluation are valid concerns which need to be dealt with in the economic analysis of new technology.

Price variability and the effects of government policy and market development mean that profitability is a complicated decision which can be influenced by the farmers' marketing strategies and by macro factors outside the farmers' control. Nevertheless, farmers need to be able to devise some strategy to make a profit from a new technology. Sensitivity analysis which varies the prices and costs over the relevant range can be utilized to respond to this problem. The simple budgeting analysis of on-farm trials is usually a mean or median estimate. The variation in yield performance and prices received between farms is a useful complement to this measure.

Some of the relevant inputs that need to be costed for budgeting analysis may not have a market price. In the WASAT, family labor during certain periods for performing specific cultural operations, such as the first weeding, has a very high implicit value[8] and may even be constraining certain types of output expansion. Mathematical programming models take into account the implicit value of the inputs and put a cost on them (shadow price), whereas budgeting treatments make some arbitrary assumptions about the labor market. Land rental, depreciation of the capital input, and management costs are also difficult to estimate and are

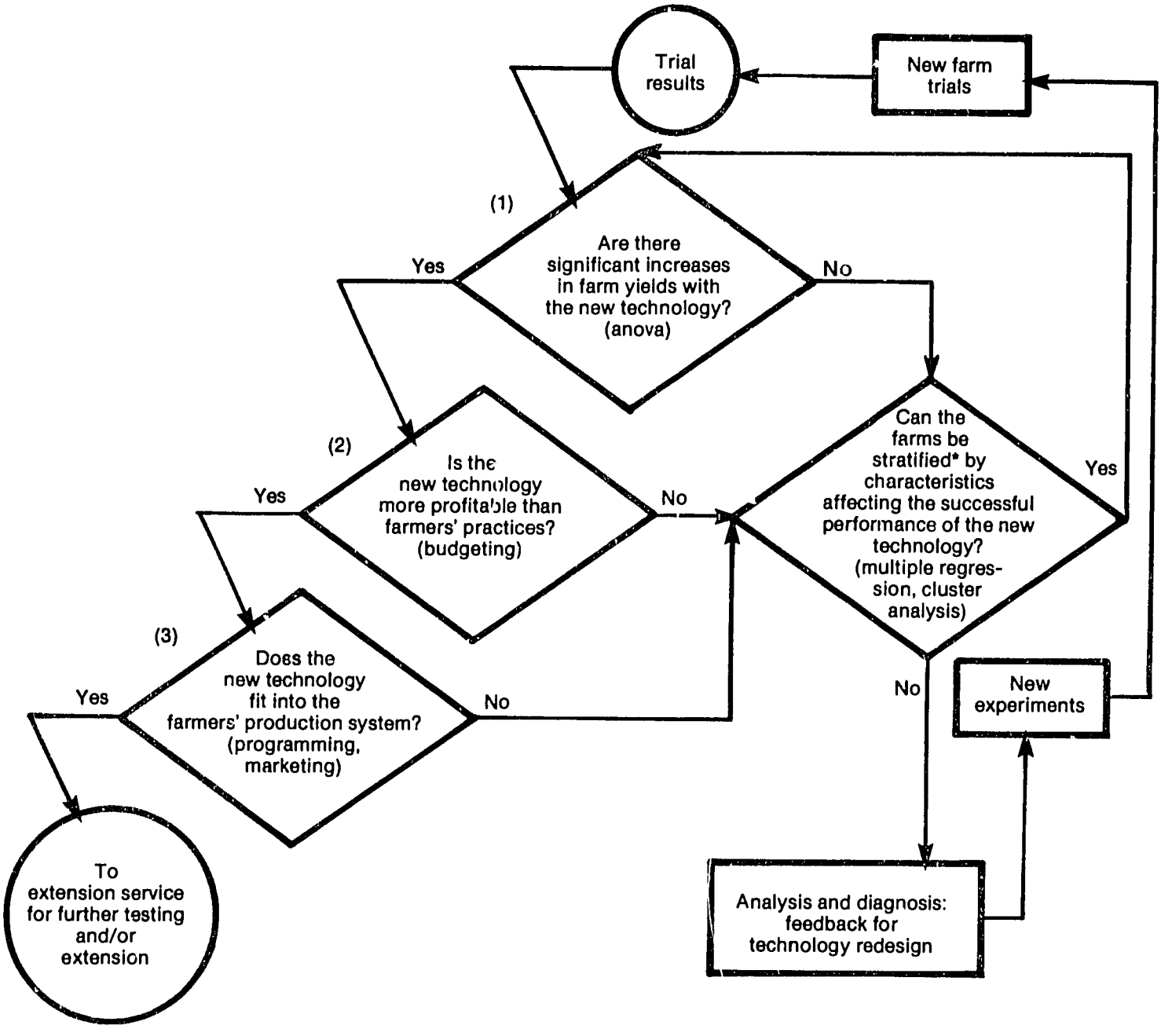


Figure 5. Flow Chart for New Technology Evaluation in Farm Trials.

Source: Sanders and Lynam, 1982, p. 100.

* In any of the three stages of evaluation a new technology treatment may not pass the criteria based upon mean values. Then a stratification of farms is attempted upon an a priori basis. For example, the performance of a fertilizer technology would be influenced by the soil types. If there were two types of soils and there was a return to fertilization on one and not the other, then stratification into these two groups would be undertaken. For the subgroup of farms where the fertilizer technology was effective, the three stages of evaluation would commence again. The subgroup where fertilization was not effective would raise research questions for analysis and diagnosis as indicated in the above flowchart.

often omitted in the simple or partial budgeting. In spite of the difficulties of costing some inputs and the price variation, profitability comparisons with sensitivity analysis give substantially more information than yield comparisons.

Nevertheless, even profitability is not a sufficient criteria for farmer acceptance. A new system may be profitable but may require more labor at a peak period than the farmer can release from his other operations or the new activity may have much higher capital requirements than the farmer can obtain. The third question (Figure 5) is whether the technology fits into the farmers' production system. Whereas simple budgeting can indicate that one activity is more profitable than another, mathematical programming takes into account all other present and potential activities and the available on-farm and off-farm resources. Utilizing this technique and the above information, an estimate of the extent of potential adoption of a new technology on a representative farm can be made. Moreover, the farm-level constraints to the further adoption of more profitable activities can be identified. Clearly, the value of this modeling will depend upon the researcher's understanding of the farming system and his ability to simplify the model to the essential elements.

These mathematical programming whole-farm modeling techniques have been operationalized at the farm level for approximately twenty years, so their practical value in assisting public and farmer decision-making in developed countries has been repeatedly demonstrated (Doster, et al., 1981; McCarl, 1982). One difficulty in the implementation of this technique in developing countries has been the computer requirement; however, the rapid diffusion of micro computers to the developing countries is resolving this problem even in the WASAT. Nevertheless, there is a necessary time investment involved in training the technicians, economists, and agricultural scientists to implement these models and to interpret the results.

Mathematical programming forces researchers to focus their data collection on the systems problems of production in a whole-farm context (for reviews and applications see Anderson et al., 1985; Ghodake and Hardaker, 1981; Roth, et al., 1986). Simple technical coefficients representing the relationships between inputs and outputs and the resources available to the farmer are the relevant data sets for evaluation of profitability and the fit of the new technologies into the farmers' systems of production. Adjustments in the modeling can be made for more complicated farmer behaviors than profit maximization. Risk avoidance can be explicitly included in the analysis with programming. Other constraints imposed by economic and technical factors can frequently be included.

Another step in technology evaluation could be the analysis of the intra- and inter-household effects (see McKee, 1984; Nagy, Ohm, and Sawadogo, 1986). There has been much concern recently with the role of women in farm production and consumption analysis; more specific consideration of their roles in land use, investment, and consumption decisions are warranted. Moreover, specific technologies could have equity effects on

different types of farms, and policymakers are often concerned with these potential outcomes.[9]

Many other considerations could also be raised, such as environmental concerns or the cultural trauma often associated with economic or institutional change. However, the emphasis of this paper is responding to the three questions in the flow diagram of Figure 5. Positive answers to these questions have been associated with farmer adoption of new technologies in both Colombia (Sanders and Lynam, 1982, p. 104) and Burkina Faso (Sanders et al., 1985, pp. 24-28) thus providing support for the evaluation criteria presented here. These evaluation criteria, as reflected in the three questions of Figure 5, appear to be logical, simple, and powerful for undertaking farm-level evaluation of new technologies.

Micro vs. Macro Approaches to Farming Systems Research

The farming system fits into and is affected by many larger systems. Agricultural policy, the availability of inputs, and the functioning of the product markets all affect farm-level decisions about new technologies and farm-level planning for the development of new technologies.

The most conservative approach in on-farm technology development is to assume that all these systems are not evolving and to attempt to develop new farming systems for the present levels of development in the other systems. In the WASAT, this orientation would precipitate a search for minimum input cost systems, such as:

a) new varieties used without chemical inputs such as inorganic fertilizer;
b) higher densities;
c) different planting dates;
d) different rotations;
e) more systematic use of multiple cropping;
f) more utilization of on-farm inputs such as mulch and manure.

These types of marginal changes are attempts to obtain small yield increments utilizing either available resources on the farm or an input, such as a new variety, which requires a minimal cash expenditure. One-input changes of available resources such as planting dates and rotations are easy for farmers to implement and observe and many farmers carry on small experiments of this type. The observation that farmers are not utilizing these adjustments appears to be good evidence that there are technical reasons for them not to utilize them. Generally, the yield effects of the small adjustments are either very small[10] or under certain natural conditions, they precipitate other problems in the cropping system. For example, in Colombia, higher field bean densities significantly increased disease incidence even with spraying (CIAT, 1979, p. 92).

In the last decade the French international agricultural research institute (IRAT) has been joined by three other institutes (CIMMYT,

ICRISAT, and IITA) in the WASAT. Their principal research activity has been the development of new food crop varieties, especially cereals. Yet few cereal varieties have been successful enough to displace local cultivars. Matlon (1985) estimated that the new cereal varieties presently occupy less than 5% of the WASAT crop area. In our view, new varieties unaccompanied by other inputs belong in this group of marginal changes which have had little impact. Why? Much of the WASAT is characterized by inadequate and irregular rainfall and low fertility soils. These are difficult agricultural conditions for one-input changes. Therefore, it appears that WASAT farmers will need to utilize higher levels of purchased inputs and to take more risks in order to increase their incomes.[11]

Presently, the level of purchased input utilization in the WASAT, especially chemical inputs, is extremely low. The eight Sahelian countries have the lowest chemical fertilizer consumption in the world at less than 3 kg./ha. on crops. Animal traction is still in the introductory stage at less than 15% of the farmers in the WASAT (Matlon, 1985). Moreover, only a small portion of the cereals are marketed (less than 10% in FSU sample villages on the Central Plateau in Burkina Faso). Only 3% of the cropland in the eight Sahelian countries is irrigated (Matlon, 1983). With these low levels of input use and infrastructure, it does not appear to be appropriate to develop new technologies for high levels of input use. However, it is important to make improvements in the marketing systems so that moderate input levels can be utilized and there will be increased marketing of the cereals.

Marginal changes such as the minimal input utilization changes discussed previously are not expected to be sufficient to interest farmers or to lead to sustained yield increases. Moderate input levels, including chemical inputs, are expected to be necessary to obtain significant yield increases, which fit economically into the farmers' production systems (see Chapter V for specific details on chemical fertilizer). Hence, as new technologies are being developed and implemented over time, input and product marketing institutions must also evolve. The development of these markets may require governmental support and further research. The efficiency of the para-statal product marketing agencies and the role of private and public institutions in input markets are two primary issues of concern in the present agricultural development literature on Sub-Saharan Africa.

What role should FSR projects have in influencing agricultural policy and other macro issues? Historically, there has been an "urban bias" in agricultural policies in most WASAT countries. To keep food prices low for urban consumers, WASAT governments have frequently intervened via para-statal marketing organizations. To compensate farmers for the low product prices, these same governments often have provided input subsidies to farmers. Presently, the World Bank and U.S. AID have been pressuring WASAT governments to eliminate these input subsidies.[12] At least in the short run, this will reduce the profitability of agriculture, discourage investment in agriculture, and delay technology adoption. Part of the evaluation

of new technologies by the FSR program should include some sensitivity analysis to estimate the farm-level effects of various agricultural policies, including the elimination of input subsidies.

In the recent summary of FSR for the World Bank (Simmonds, 1984), a distinction was drawn between modifications to present farming systems and entirely new systems of production. Improved agronomy with moderate levels of inputs and ultimately introducing new varieties for these improved systems would be in the first category (and see Chapter V for concrete examples). However, many of the poorer, more marginal environments in the WASAT ultimately will need to gradually withdraw from crop production and move into grazing systems or forestry. Crop farming in the WASAT migrated further north after the high rainfall period of the fifties. As yield increases are attained in those regions of rainfed agriculture with more potential and in the river valleys and irrigated areas,[13] some present crop areas can be returned to more extensive agricultural systems. Farming systems research will need to make some decisions about the regions with the most agricultural potential. For those truly marginal regions, more comprehensive systems changes may be necessary than are customarily evaluated in farming systems research.

National policy factors and national agricultural development planning cannot be ignored in FSR. Many of these macro factors and evolving changes need to be explicitly incorporated into the analysis of which technologies and regions are appropriate for evaluation. Nevertheless, it is recommended that modeling concentrate on the farm level. Without much better micro data and analysis than is presently available in most developing countries, extending farm models to sector analysis seems to be only a training device for economists rather than a useful exercise to enlighten agricultural development planners. As the micro-modeling foundation is improved in the next five to ten years, the agricultural sector models will be able to give a more useful input into agricultural policy formulation in the WASAT countries.

Which agencies should undertake the on-farm testing?

FSR presently takes five to ten percent of the budgets of several IARCs (Simmonds, 1984, pp. 67, 68) and the IARCs have generally taken a leadership role in field application of on-farm testing. The long-run, frequently stated objective of the IARCs is to turn this activity over to the national agricultural research systems (NARC). The rationale is that the on-farm trials give very location-specific results. The IARCs can develop methodologies and demonstrate the utilization of new research activities to the NARCs, but, ultimately, larger numbers of on-farm trials in many regions will need to be undertaken in developing countries to evaluate the diverse technologies being produced in the IARCs and NARCs. Not only does the scale of this testing make it infeasible for the IARCs to undertake all of it themselves but also much of the testing will be outside the commodity mandates of the individual IARCs.

The institutional placement of on-farm testing depends upon the relative importance of the two clienteles for the products of the research, at a given stage of technology development. These two potential clienteles are the extension service and the agricultural researchers. On-farm trials which are successful[14] give important information to the extension service and to those public officials involved with agricultural policy. On-farm trials which are not successful give feedback on farm-level problems with the technologies to researchers at the experiment stations in both the national and international centers.

If the primary emphasis of the on-farm trials needs to be on feedback, then there are two problems with the present location of most farming systems research in the IARCs. First, several of the centers put the principal emphasis of their on-farm trials on providing information for the NARCs and the extension services (Simmonds, 1985, pp. 92-97). Presently, there is less concern with feedback from the on-farm trials to IARC researchers on the relevance and problems of the technologies they are developing. Organizationally, it appears to be very difficult for a division of one institution to serve for very long as an effective critic of its own activities.

Secondly, most of the IARCs are crop-breeding institutions, including CIMMYT, IRRI, CIAT, ICRISAT, ICARDA, and IITA. Two of these centers, CIMMYT and IRRI, have been very successful in producing new varieties for those environments with adequate, assured water availability and moderate to high levels of input utilization. However, in most of the harsher environments, including the WASAT, where these conditions are not met, improvements in agronomy to attain moderate purchased input levels may need to precede the introduction of new varieties. On-farm testing undertaken or financed by the IARCs tends to concentrate on the varietal effect since that is their mandate. In these harsher environments, institutions other than the IARCs (or even the NARCs which receive IARC assistance of new germ plasm) may need to do the on-farm testing.

This on-farm testing in harsher climatic regions, such as the WASAT, would concentrate first on identifying agronomic improvements, i.e., the combination of measures to improve water retention and soil fertility. At a later stage the IARCs and NARCs could develop new varieties for these improved (but not high input) production systems. The main points here are that, at least in the WASAT stage of agricultural development, the principal focus of on-farm testing will need to be on feedback to the research station and the principal focus of research on agronomic improvements.

On-farm testing can be considered either as the last stage of the agricultural research process before passing the innovation on to the Extension Service or the first stage of the Extension process before demonstration trials and active diffusion measures. Clearly, there needs to be interaction between the NARC and the Extension Service consisting of the regular exchange of information and even planning of the on-farm trials. If there is sufficient exchange of information and collaboration

in on-farm trial design, the institutional location of these trials will be less important.

In summary, on-farm trials will need to be undertaken by most agencies involved in agricultural experimentation in the WASAT. Communication barriers are sufficiently large between scientists and farmers that this type of intermediate activity is expected to be necessary for several decades since the IARCs, NARCs, and other agencies apparently need this source of feedback on the performance of their technologies. Since we have been stressing the importance of feedback all through this chapter, we argue that the on-farm trials should be located in the research rather than the extension entity so that feedback results are more readily acceptable at the experiment station.

As on-farm trials move into the NARCs and are financed by their own internal financial resources, lower cost methods for conducting on-farm trials must be sought. These trials tend to be very intensive in their use of highly qualified scientific manpower for planning and evaluation. Their execution requires good logistic support and training for a large number of field workers. It would appear that, in the WASAT, external financing and external scientific manpower will be necessary for some time to continue high levels of on-farm testing.

Conclusions

Defining farmers' constraints to increasing agricultural production is a complicated task best illustrated by example. In the conclusions to this report (Chapter VI) we return to this problem to illustrate the contribution of the Purdue farming systems project to constraint identification in the WASAT. Meanwhile, the survey process can be divided into an initial or baseline study, which describes the farmers' production and household systems and supplementary or diagnostic surveys, which investigate particular research areas as they arise. For the baseline study, the in-depth village-household production and consumption analyses frequently undertaken by anthropologists and sociologists seem especially relevant to an understanding of the farming systems in the areas specifically targeted for further research activity during the on-farm stage of FSR. Supplementary diagnostic surveys can then be undertaken in response to specific objectives of the farm-level work, especially the on-farm testing of new technologies. These will often be within the disciplinary area of agricultural economists. In the modeling stage of the evaluation process there will frequently be a need for supplementary farm business or household information.

One primary recommendation here is that the on-farm testing phase of the FSR begin in the first production season. Agricultural scientists will generally have a series of recommendations of component parts for farm testing. Putting these individual factors together into technology packages and testing them under farmers' conditions will help to further develop their understanding of farmers' objectives and systems. The

agricultural scientists will generally have much more interest in field experiments than in the diagnostic surveys. In this initial stage of on-farm testing the principal direction of information flow will be feedback to the researchers as the packages are expected to have either technical or economic problems impeding their acceptance by farmers.

Multi-disciplinary collaboration, especially between the agricultural scientists and economists, is essential for the on-farm testing. Agricultural scientists know well the mechanics of the testing process. Economists understand the farmers' objectives. Both need to collaborate to understand the interactions and complexities of farmers' systems of production. There should be collaboration in research design to avoid replicating experiment station trials and to obtain the necessary data for economic analysis.

On the farm, the treatments are generally different systems of production rather than individual factors. The analysis proceeds from a statistical analysis of the significance of yield differences to economic concerns with profitability and the fit into the farmers' systems of production. The comparison between treatments analyzes the potential benefits to the farmers from new technology adoption since the control is a proxy for the farmer's system of production. The simplest economic analysis is the evaluation of profitability using partial budgets. However, this type of analysis is not as simple as it appears because of price variation and the difficulty of attributing prices to some production factors. Generally, an attempt is made to overcome these budgeting problems with sensitivity analysis.

The final step in the evaluation is to consider the potential fit of the activity into the farmers' systems of production with mathematical programming. This whole farm analysis simulates the farmers' decision-making process by including information on all present and potential activities using the data on on-farm and off-farm resource availabilities. New systems of production that pass through all three stages of this evaluation are expected to be adopted by farmers. There is some adoption evidence from both Colombia and Burkina Faso supporting the above assertion.

In the harsh environment of the WASAT, given the very low utilization of purchased inputs at present, marginal agronomic changes such as density, timing, or even varietal change are expected to have little or even negative impact. Larger systems changes involving technologies which simultaneously augment water conservation and soil fertility are hypothesized as necessary in order to raise yields sufficiently so that these new systems not only yield more than farmers' practices on their own fields but also are profitable and fit into farmers' production systems.

National economic and agricultural policies can have a large impact on technology evaluation and even the planning of FSR. Policymakers need to be concerned with creating an environment in which farmers can make money from adopting new technologies. In the short run in the WASAT the

elimination of input subsidies, especially if ceilings are retained for product prices, will make it more difficult for farmers to profit from new technology adoption. By evaluating the impact of different agricultural and economic policies on the farm-level profitability and potential adoption of new technologies the FSR program may be able to help influence governmental policy formation.

Another impact of national policy is on agricultural development planning. Frequently, FSR programs are designed for marginal agricultural areas. Alternatives to developing technologies for these regions may be public health investments in river valleys and yield-improving strategies in the dryland regions with better agricultural resources. If yields can be sufficiently improved for the higher resource regions, some shifting into livestock or even forestry may be appropriate land-use decision for the more marginal agricultural areas. For these types of land-use changes government would need to finance the human resettlement costs. Change in agricultural activities of this magnitude are not generally included in FSR. Hence, Simmonds (1984, p. 121) developed a new term for it, New Farming Systems Development (NFSD).

In the WASAT a prerequisite to new variety development appears to be the simultaneous utilization of moderate input levels to improve water retention and soil fertility. Once these agronomic improvements are in place, new variety introduction is expected to have more potential for success than at the present time. Some of the on-farm trials in the WASAT may need to be undertaken by agencies whose principal activity is <u>not</u> new variety development[15].

The on-farm testing can be either the final step in the research process of the NARC, IARC, or other research institution or the first step in the Extension Service before demonstration trials or other dissemination activities. The institutional location should depend upon whether the primary product is feedback on technology improvement to experiment station researchers or "feedforward" of technologies to be disseminated by the Extension Service. Since the process of feedback to researchers is considered to be the most important objective of on-farm testing in the early stages of agricultural technology development in the WASAT, our institutional preference for the location of these trials is with the national agricultural research centers (NARCs) rather than the national extension service. The scientists in the on-farm trials will know how to convince the scientists on the experiment station of the validity of their results. Some of them may even fulfill a dual role, working on both the experiment station and the on-farm trials.[16] As more technology is validated in the on-farm trials and can move on to the Extension Service, the returns to investments in the institutional ties between the NARCs and the Extension Service will be increased.

FOOTNOTES

[1] This type of information flow is customarily referred to as "feedback." Farming Systems and other research programs also attempt to provide information on new technologies to farmers and extension agents. Any agricultural research program ultimately needs to have an impact on the well-being of farmers in order to survive. Since the economic importance of this directional flow of information to farmers is obvious, we consider it to be more important to stress here the importance of the feedback to researchers so that they are more effective in doing their job, i.e., producing new technologies.

[2] Dillon (1976, pp. 6-7) contrasts philosophic differences of scientific investigation into two approaches. "Reductionism implied reducing phenomena to their more basic (and hopefully independent) parts, analyzing these parts as independent entities to explain their behavior, and then aggregating these explanations as an explanation of the phenomenon under study.... Reductionism abetted and fostered the proliferation of specialized deafness and tunnel vision in the form of independent scientific disciplines."

Since the fifties, reductionism has been increasingly seen as an inadequate basis for science to either understand or to manipulate and control its environment. An alternative approach is the systems or holistic approach. This is a multi-disciplinary approach in which "explanation then proceeds in terms of the role or function of the part in the larger system(s)."

[3] Clearly, he/she will be exposed to all the other types of constraints but disciplinary blinders often exist especially for those involved in their own research programs.

[4] A recent international agricultural research center meeting for the planning of on-farm trials in Africa concluded that the initial description and diagnostic activity of the FSR should be rapidly implemented so that a crop season for experimentation is not lost (unpublished summary of meeting notes, ILRAD, Oct. 1984). Diagnostic/survey activities and farm-level experimentation can continue simultaneously. In fact, the farm-level experimentation will require additional diagnostic/survey activities to evaluate the economic potential of the new technology.

[5] The diagnostic surveys of economists have not been nearly as useful for a comprehensive understanding of the farming and household systems as those of the anthropologists. However, the utility of the economist on multi-disciplinary teams to undertake and evaluate on-farm trials has been repeatedly demonstrated and is now widely if not universally accepted (Simmonds, 1984, pp. 24, 71-75, 125). The other social scientists have not yet demonstrated their capacity to work on these types of teams. They appear to be in the position of defining their role, a position similar to that of the economists about a decade earlier.

[6] Generally, soil fertility is higher on the experiment station and the incidence of diseases and insects is greater than on the surrounding farms due to the repeated intensive cultivation of the same crops. However, on the experiment station, the high levels of non-treatment inputs such as agricultural chemicals can reduce the levels of insects, diseases, and weeds to levels even lower than on the farmers' fields. For farmers these levels of chemical control are often not profitable.

[7] Occasionally the impact of one or two components will be estimated, as with fertilization and tied ridges (a water-conservation technique) alone and in combination in the Burkina Faso FSU program.

[8] If the weeding is not done opportunely, there can often be a yield decline. Moreover, all farms in a given region will be performing these types of operations at approximately the same time. Hence, it will be very difficult for farmers to hire temporary labor away from their family operations. So the implicit value or productivity of the family labor becomes very high in these particular tasks at certain critical times.

[9] A more comprehensive agricultural policy analysis would include the macro effect of new technology introduction on prices as is done in agriculture sector models. But because so many other structural changes are occurring at the same time this price effect is not considered to be very important, at least in the initial stages of technology development.

[10] Those advocating these types of planting density, date, or other cultural system change generally are expecting yield increases of only 10 to 20%. This type of yield increase is very difficult for the farmer to see and could easily disappear as on-farm trials change from researcher to farmer management. New agronomic system changes are expected to take time for farmers to master if a series of component part changes are implied and/or timeliness of the relevant operations is also important. Hence, the yield differences of these minimal changes, even if they truly exist, will often disappear in the learning-by-doing effect.

[11] Once farmers are utilizing moderate purchased input levels, it will be very important to systematically evaluate the impact of these marginal changes, especially new varieties and more intensive cropping systems.

[12] By removing all input subsidies and other price distortions or interventions, governments and international agencies can calculate the real resource cost of various alternative policies and ascertain their comparative advantage in international production. This analysis assumes that there are no differences between private and public benefits or between private and social costs. Hence, there are no externalities in the system.

Removing these price and cost distortions will facilitate economic calculations and, in the long run, welfare gains are expected. In the short run, the elimination of input subsidies is expected to sharply slow down the agricultural development process and to put upward pressure on agricultural product prices and the demand for agricultural import substitutes. Developed country exporters of agricultural products would be the principal beneficiaries of higher agricultural import levels in the developing countries.

13 In the river valleys and irrigated regions human health constraints may be the principal factor limiting agricultural development. River blindness has been a serious problem in many of the Burkina Faso river valleys. An erradiation program has now at least temporarily eliminated this problem. In the irrigation projects the widespread incidence of bilharzia substantially reduces labor productivity.

14 By successful we mean passing the three evaluation criteria recommended in Figure 5. Clearly, agricultural scientists will also be interested in those technologies being passed on to the Extension Service for diffusion. We are stressing here their interest in feedback in order to resolve those problems in their technologies which came to their attention because of the results of the on-farm trials.

15 We would expect that those agencies principally concerned with varietal development would emphasize varietal testing in their on-farm trials. The on-farm trials are important activities for institutions primarily concerned with breeding. Nevertheless, a third party such as a university may be necessary in order to carry out the farm trials without preconceived notions which would emphasize certain varieties or other types of technology.

16 The differences are so great between the experiment station and the farm-level definitions of constraints and relevant research problems that one of the field agronomists from this project even proposed that all agricultural scientists working on the experiment stations in the WASAT should have some involvement with on-farm trials.

CHAPTER IV

PRODUCTION CONSTRAINTS OF THE WASAT FARMING SYSTEMS

The WASAT is not as well endowed with a climate or soil resource base as most of the populated areas of the world. This chapter elaborates on the major physical and resource endowment constraints of the WASAT and describes cropping patterns, farmers' goals and objectives, and modern input use.

Climate

The WASAT region is a transition zone between the northern desert and the humid tropics of the south. There are three distinct seasons: warm and dry from November to March, hot and dry during March through May, and hot and wet from May to October. Harmattan conditions (hot, dry, dust-laden winds) exist during the November to March period.

Rainfall in the May to October agricultural season over the entire WASAT ranges from 200 mm in the north to 1300 mm in the south with potential evapotranspiration ranging between 2200 mm in the north to 1600 mm in the south (Nicou and Charreau, 1985). Since the mid-sixties, annual rainfall has averaged 100 to 150 mm below the long-term average within each isohyet (Dancette, 1977). Thus the isohyet levels delineating the climatic zones in Figure 1 would be at lower levels if more recent rainfall data were used.

Rainfall is extremely variable over time and over space. Nicholson (1982) states that in normal rainfall years, 40 to 50% of individual weather stations experience below-normal rainfall. Rainfall variability at individual stations ranges from 15% of the long-term average in the south to 50% in the north (Nicholson, 1982). Also, the number of below-normal years tend to exceed the number of wet years. The long-term average rainfall is inflated by a few extremely wet years (Nicholson, 1982). The area also has a long history of intermittent droughts and wet spells.

Soil Fertility and Water Retention

Soils in the WASAT are predominantly sandy, red alfisols, low in organic matter and exchangeable cations with a soil texture high in sand (60-95%) and low in silt and clay content (Matlon, 1985; Nicou and Charreau, 1985). The soils tend to be deficient in phosphorous and nitrogen. Long fallow periods can restore soil fertility but phosphorous and nitrogen deficiency symptoms have been observed shortly after the land is put into cultivation (IFDC, 1985). The phosphorous sorption capacity of WASAT soils vary widely but is generally low, decreasing the agronomic effectiveness of phosphate fertilizers (IFDC, 1985). Nitrogen can be quickly exhausted in these fragile, poorly buffered soils (IFDC, 1985). The soils contain only weak aggregates and in many regions the soil surface

dries after a rain and forms a crust which restricts water infiltration and aeration (Kowal and Kassam, 1978). These soil properties combined with high intensity rainfall lead to water retention and erosion problems. In the dry season, the soils harden, making pre-plant cultivation difficult and almost impossible by traditional methods until there is a major rain (Kowal and Kassam, 1978).

The quality of the land in terms of fertility and organic matter content varies greatly in farmers' fields. Land quality and soil water retention are highly correlated with topography and distance from the compound area around the living quarters. The quality and water retention ability of the soil deteriorates as one moves farther up the toposequence and away from the compound area, thus requiring different cropping and management strategies by the farmer (Stoop, et al., 1982).

Although more productive vertisols and hydromorphic soils are found along river valleys, the presence of Onchoceriasis (river blindness) in many of the river valleys has made them uninhabitable in the past.

Labor Availability

Labor shortages exist in the critical planting and weeding periods (FSU/SAFGRAD, 1983). Planting of millet and sorghum begins with the first significant rains in May or June. This is followed by rice, groundnut, and maize planting in combination with the sorghum and millet first weeding activities. Depending on the level and distribution of rainfall, fields may require resowing, transplanting, and/or thinning. Usually a second, and at times a third, weeding will follow. Most of the planting/first weeding period occurs over a six-week time period with the household supplying the labor.

When farmers were asked why they did not hire more labor for first weeding, their reply was "Because there is no one to hire then, everyone is busy with their own weeding" (FSU/SAFGRAD, 1983). Households do not generally hire labor from other households because cash and food reserves at this time of year are at their lowest and not sufficient to pay laborers a wage rate (or its equivalent in food) equal to the opportunity cost of working their own land.[1] Also, few laborers are in the labor market at this time because households have control of their family labor and utilize it for their own production needs (Kowal & Kassam, 1978).

Cropping Patterns

Cereal production is the dominant agricultural activity in the WASAT (Kowal and Kassam, 1978). Regional cropping patterns in the WASAT differ--the most notable difference being the increasing dominance of millet over sorghum, maize, and root crops as soil fertility and rainfall decrease from south to north. About 80% of the cropped area in the WASAT is intercropped--cereal/cereal and cereal/legume are the most common (Fussell and Serafini, 1985; Sawadogo, et al., 1985). Cowpeas are usually intercropped

with millet or sorghum at low densities of 1000 to 8000 plants per hectare. The main cash crops in the south include cotton, groundnuts, and bambara nuts. Small amounts of rice are grown in the bottom lands and irrigated areas.

At the farm level, land quality, the water retention ability of the soil, and labor availability are the dominant factors in farmers' cropping decisions (Lang, et al., 1983). The staple crops of maize, sorghum, and millet, receive the highest priority of land and labor resources. Drought tolerance of the crops are matched with soil fertility and toposequence. Maize, which is less tolerant to drought and low soil fertility than either sorghum or millet, is planted near the village compound on the more-fertile compound field. This field, ranging in size from .1 to .2 ha., is used as a dump for night soil, animal manure, stubble, and other organic material. Sorghum is planted on the lower areas where there is slightly more water accumulation and where the soils are more fertile than the poorer soils further up the toposequence (Stoop, et al., 1982). The more abundant but poorer land is planted to millet, which has the most tolerance to drought and low soil fertility. Farmers say that in the worst rainfall years, some millet can always be harvested.

Millet and sorghum can be found growing in the next higher soil fertility gradient than is dictated by their drought tolerance ability but maize and sorghum are rarely grown on a lower soil fertility gradient. Farmers say that white sorghum is preferred because it stores twice as long as millet; however, more sorghum is not sown because of limited good quality land and because sorghum is more vulnerable to parasites such as striga. Maize and sorghum planting is thus constrained by the availability of high quality land whereas the millet area is constrained by the labor supply in the planting/first weeding period.

In the old settlement areas, cereal yields are declining in response to lower soil fertility caused by the decrease in the fallow period and lower average rainfall over the last decade (Lang, et al., 1984). As the soil fertility declines, sorghum is being replaced by millet, which yields better on the poorer soils. Farmers in the village of Nedogo say that much more sorghum was planted in the village when they were young than is planted now (Ames, 1986).

Farmer Goals and Objectives

Norman (1982) states that the most important differences among farming systems come from the constraints peculiar to the region and not from differences in farmer aspirations (which include higher incomes, effort reduction and risk avoidance). Farmers in older settlement areas have constraints and endowments which differ from those of farmers in frontier villages. Farmers in the older settlement areas of Burkina where access to land is limited and soil fertility low indicated uniformly that their only goal was "subsistence" (FSU/SAFGRAD, 1983). This means harvesting enough sorghum and millet in November to feed their families until the beginning

of the August maize harvest that provides food during the "hungry" period--the period between ending cereal stocks and the new harvest (FSU/SAFGRAD, 1983). When asked to specify other goals and objectives, the first priority was the payment of a head tax, and, if resources remained, meeting "urgent needs" which were listed as medical. Other priorities were to reward the family with clothes for their work during the cropping season and to "greet" their in-laws or arrange marriages (FSU/SAFGRAD, 1983).

On the frontier, where access to fallow land is not limited, half of the farmers gave subsistence oriented responses that were similar to the responses given in the older settlement areas. However, half of the farmers responded that "We were once concerned only with 'survival' but now we also think of accumulating wealth". When asked "What is wealth?", they replied "cattle" (FSU/SAFGRAD, 1983).

The survey results indicated that although farmers in the WASAT in general are subsistence oriented, the goals and objectives of farmers differ given different constraints. This is evidenced by the total subsistence orientation of the sample of farmers in the old settlement villages versus the orientation of those farmers in the frontier village, who indicated wealth accumulation as one of their main goals. Higher soil fertility and access to land at the frontier has permitted farmers to look beyond subsistence goals. This appears to demonstrate that if, through technological introduction, some of the constraints to increasing yield in the WASAT can be alleviated, the aspirations of farmers will allow technology adoption to occur (at some level of profit, effort, and risk).

Modern Input Use

Except for the higher rainfall regions of the Sudano-Guinean region and some river valleys, credit and modern inputs such as fertilizer, pesticides, herbicides, and improved varieties are not widely used in the WASAT. Even in these regions of higher rainfall, purchased input utilization is concentrated on the export crops, cotton and groundnuts. FAO fertilizer statistics indicate that NPK use in eight Sahelian countries averaged less than 3 kg/ha as compared to 73 kg/ha in Asia (Matlon, 1985). Less than 15% of farmers use animal traction in the WASAT (Matlon and Spencer, 1985). Animal traction is used for shallow land preparation, plowing, and shallow weeding, but utilization rates are low and farmers seldom are equipped to do more than one mechanized operation (Jaeger, 1985).

Neither input nor product marketing infrastructure nor a research and extension service similar to that developed for cash crops in the WASAT pre-independence era (pre-1960) was ever developed for food crops. In the Colonial period, food requirements were met by the subsistence-oriented agricultural system. There was little export demand for food crops such as sorghum and millet (World Bank, 1985). Since the late 1960's, however, rapid population growth and lower food crop yields due to lower rainfall levels and declining soil fertility have substantially increased food crop

demand to the point where food security is not assured in most regions of the WASAT. Expanding cereal imports have accompanied this trend.

Even with the population pressure and increased food demand since independence, an input and product marketing infrastructure for food crops has not developed. Poor fertility soils, erratic rainfall distribution, and low soil water retention have led to highly variable between-year yield responses to many land-substituting inputs. For example, the response of fertilizer is highly dependent upon the availability of sufficient water at several critical periods. Thus, fertilizer utilization can be very risky. Similarly, improved varieties have not done well under traditional management conditions (Matlon, 1985).

Labor-saving animal traction technology is not widely used in the WASAT in spite of potentially high rates of return. Present internal rates of return of 10% in old settlement areas (Nedogo) and 20 to 30% at the frontier (Diapangou) have been estimated, but higher rates of return could be achieved with higher utilization rates, principally through expansion of the number of mechanized agricultural operations (Jaeger, 1985). Most animal traction farms observed in Burkina Faso mechanized either the land preparation or the cultivation operations, but not both. Problems of obtaining high utilization rates stem from: small size farms, inappropriate and/or incomplete set of implements, poor animal health and nucrition, and poor management (Jaeger and Sanders, 1985). Higher utilization rates and the full benefit of mechanization are not obtained by first-time animal traction users because learning curves can be as long as five years (Jaeger and Sanders, 1985). Few animal traction extension programs exist which train farmers and draft animals and, thus facilitate animal traction usage.

In summary, low soil fertility and low soil water retention, low, variable and unpredictable rainfall in combination with a high evapotranspiration rate, labor shortages in the critical planting and weeding periods, and the limited access to land in old settlement areas are the major physical and resource endowment constraints to increased cereal yields in most of the WASAT (Matlon, 1985; Nagy, et al., 1985; Lang, et al., 1984). The physical environment makes new technology adoption in the WASAT risky. The national research institutions, extension, and input and product marketing infrastructures to support new technology adoption and dissemination are at a low level. Thus farming systems on the frontier continue to be bush-fallow systems that rely on available land and family labor inputs with little utilization of purchased inputs. Farming systems in the older settled area have been shifting to more millet production and yields have declined and stabilized at low levels.

Despite the current situation in the WASAT, recent research findings suggest that a Malthusian perspective can be averted. Several on-farm evaluated technologies have been shown to be both agronomically and economically feasible in increasing cereal production and others have promise for the future. A review of the proposed technologies and farm management practices for the WASAT is the subject of the next chapter.

Footnotes

[1] Whole farm modeling results indicate opportunity costs of labor in the last two weeks of the planting/first weeding period to be 365 and 181 FCFA/hr respectively for manual tillage farmers which is in contrast to the wage rate of 30 to 50 FCFA/hr (Roth, et al., 1986).

CHAPTER V

TECHNOLOGY DEVELOPMENT TO INCREASE CEREAL PRODUCTION IN THE WASAT

Introduction

This chapter reviews the technologies and farm management techniques that have been proposed for alleviating the production constraints in the WASAT. This review uses agronomic and socio-economic data and information from the Purdue FSU program supplemented by other research from the area. The FSU program conducted research in three climatic zones with village research sites in the southern portion of the Sahelo-Sudanian zone, in the Sudanian zone, and in the northern portion of the Sudano-Guinean climatic zone (Figure 2). Thus FSU findings and the review of most of the technologies and recommendations reflect this orientation.

As each technology is discussed, it is evaluated as to the feasibility of its utilization by farmers within the short run (0 to 5 years), the intermediate run (5 to 15 years), and the long run. The criteria used in the evaluation attempt to follow the strategy used by farmers in their adoption process (see Figure 5 in Chapter III and Table 1 in this chapter).

Socio-economic research suggests that farmers do not necessarily adopt technologies as a "package" but rather adopt single technologies or "clusters" of technologies en route to total package adoption (Byerlee and Hesse de Polanco, 1986; Mann, 1978). This is in spite of the fact that the largest impact on yields comes about when various methods (technologies) are used in combination or as a package. The farmer's strategy seems to be to adopt the technologies of the package sequentially based on availability, technical viability in the field, economic profitability and risk considerations, and the resource endowment fit of the technology (i.e., labor and land constraints) within the farming system. The technologies within the package that best exhibit the above attributes will be selected first by the farmer. Other technologies will be added only after the farmer has had positive experience with the already adopted technologies and when the above attribute requirements are again met. Thus, while farmers can be presented with a package of technologies, there seems to be an agronomically and economically logical sequence by which technological adoption will occur. Information on the likely adoption pattern sequence of proposed technologies is important for focusing research, extension, and government programs.

In this chapter, available agronomic, technical, and socio-economic research findings are used to review and sequence the proposed technologies and farm management practices for the WASAT. For example, research findings from on-station and on-farm research trials are used to assess technical viability in the field. Economic budget analysis, and benefit-cost

Table 1. Present technical and economic feasibility and time frame of proposed technologies and farm management practices for the WASAT.

Technologies and Farm Mgmt. Practices	Present Agronomic and Technical Feasibility: On-Station Research	On-Farm Research	Present Economic Feasibility	Comments
Available technologies for the short run				
Tied ridging (manual)	+++ 1/	+++	*** 2/	Very labor intensive
Diguettes/dikes	3/	+++	**	Require materials (i.e., rocks)
Complex fertilizer	+++	++	*	Risk of losing cash outlay
Animal traction	3/	++	*	Preconditions (see text)
Mechanical ridge tier	+++	++	***	Requires animal traction
Potential technologies for the intermediate run				
Rock phosphate	+	-	-	Solubility & application problems
Improved varieties	++	+	-	Requires upgrading of physical environment
Potential technologies for the long run				
Manure/composting	+++	++	**	Small and finite supply
Mulch	+++	++	**	Small and finite supply
Plowing/green manuring	++	++	-	Poor draft animal health
Herbicides	++	++	-	Further research required 4/
Biol. nitrogen fixation	+	-	-	Further research required
Crop associations:				
- intensification	++	+	-	Requires upgrading of physical environment and improved varieties. Labor and management intensive.
- alley cropping	++	+	-	

1/ +++ High degree of feasibility--research supports a very good agronomic response or is technically very feasible.
++ Feasible--good agronomic response or technically feasible.
+ Limited feasibility--agronomic results often inconsistent.
- Not feasible--little evidence to support a good agronomic response or technical feasibility.

2/ *** = Highly profitable at present.
** = Profitable at present.
* = Not always profitable at present.
- = Not economically feasible at present.

3/ Not researched at the on-station level.

4/ Can be feasible for sole cropping but problems with mixture of broad and slender leaf plants in crop associations.

ratios are used to determine economic profitability. Research trial results and the incidence of cash outlay loss are used to assess risk.[1] Whole farm modeling and labor data analysis is used to indicate the fit of the technology within the farming systems. Farmers' views and comments are also incorporated.

Once the technologies and farm management practices are reviewed and sequenced for either the short, intermediate, or long run, the discussion in this chapter turns to identifying available technologies--first, for the present cereal-based farming systems and second, for a future more intensified farming system. The technologies available for use in the present farming systems are then further sequenced on a recommendation domain basis.

Proposed Technologies for the WASAT

The research that has been carried out in the WASAT, aimed at overcoming climatological and physical constraints and labor endowment shortages, is discussed under the headings: 1) soil fertility/water retention technologies, 2) labor-saving technologies, 3) improved varietal research, and 4) crop associations. Table 1 presents a summary of the technical and economic feasibility evaluation and a time frame for the availability of the proposed technologies and farm management practices.

1) Soil Fertility/Water Retention Technologies

Tied Ridges. Tied ridging technology was introduced in the 1950's in West Africa (Dagg and Macartney, 1968). On-station and on-farm research has shown that tied ridges significantly increase yields (Nicou and Charreau, 1985; Dugue, 1985, Rodriguez, 1982; Ohm, et al., 1985a and 1985b) (see Photograph 5, page 41).[2] FSU on-farm researcher-managed (TR constructed both at, and one month after, planting) and farmer-managed trials (TR constructed 4-6 weeks after planting) have shown significant yield increases and economic returns to the additional labor required for TR on maize, sorghum (Table 2, column 2) and millet (FSU 1982 Annual Report, 1983; Lang, et al., 1984; and Ohm, et al., 1985a and 1985b).[3] Manual tying of ridges is very labor intensive. The manual tying of ridges constructed with animal traction requires at least 40 man hours/ha (with very efficient laborers) and on average 75 man hours/ha whereas constructing TR completely by hand requires at least 100 hours/ha (Ohm, et al., 1985b) (see Photograph 6, page 41).

Woman planting millet by traditional manual method: no pre-plant soil tillage, no fertilization.

Soil scarification with animal traction.

Left: fertilization; right: no fertilization; foreground: droughty area in field - a typical view in the Central Plateau.

Manual construction of tied ridges in researcher-managed trial — mulch applied to some plots.

FSU researcher managed trials near Poedogo:
a. No fertilization, construction of tied ridges at planting.
b. No fertilization, construction of tied ridges one month after planting.
c. No fertilization, without tied ridges
d. Fertilization and tied ridges

Water entrapment in depressions resulting from tied ridges.

Farmer-managed plots - Left: traditional method, no fertilization and no tied ridging; right: fertilization and tied ridging.

Farmer-managed trials - Left foreground: mulch applied, no fertilization nor construction of tied ridges. Right foreground: fertilization and contruction of tied ridges one month after planting. Background: farmer's traditionally managed field.

Construction of tied ridges with mechanical ridge tier.

FSU researcher managed trial. Background: maize intercropped with cowpeas, fertilized with construction of tied ridges at planting. Foreground: maize intercropped with cowpeas, no fertilization nor construction of tied ridges.

Table 2. Economic analysis of farmer-managed trials of sorghum with fertilizer and tied ridges, Nedogo and Diapangou, 1983 and 1984.

	Treatments[1]			
	C	TR	F	TR,F
	Nedogo: 1984, Manual Traction			
Grain Yield, kg/ha[2]	157	416	431	652
Yield Gain Above Control, kg/ha	-	259	274	495
Gain in Net Revenue, FCFA/ha[3]	-	23,828	13,275	33,607
Return/hr of Additional Labor, FCFA[4]	-	238	140	172
% Farmers Who Would Have Lost Cash	-	0	27	9
	Nedogo: 1983, Manual Traction			
Grain Yield, kg/ha	430	484	547	851
Yield Gain Above Control, kg/ha	-	54	117	421
Gain in Net Revenue, FCFA/ha	-	3,510	-2,285	17,475
Return/hr of Additional Labor, FCFA	-	35	-	90
% Farmers Who Would Have Lost Cash	-	0	66	0
	Diapangou: 1984, Donkey Traction			
Grain Yield, kg/ha	498	688	849	1,133
Yield Gain Above Control, kg/ha	-	190	351	635
Gain in Net Revenue, FCFA/ha	-	17,480	20,359	46,487
Return/hr of Additional Labor, FCFA	-	233	214	273
% Farmers Who Would Have Lost Cash	-	0	21	0
	Diapangou: 1983, Donkey Traction			
Grain Yield, kg/ha	481	522	837	871
Yield Gain Above Control, kg/ha	-	71	356	390
Gain in Net Revenue, FCFA/ha	-	6,532	20,819	23,947
Return/hr of Additional Labor, FCFA	-	87	219	141
% Farmers Who Would Have Lost Cash	-	0	16	12

Source: Ohm, et al., 1985b and Lang, et al., 1984. Similar results were obtained at three other sites in Burkina.

[1] C = Control (no tied ridges or fertilizer); TR = tied ridges constructed at second weeding; F = fertilizer: 100 kg/ha 14-23-15 applied in band 10-15 cm from row at first weeding plus 50 kg/ha urea applied in pockets 10-15 cm from seed pockets at second weeding.

[2] The standard error and CV % (in parentheses) starting with Nedogo, 1984 and continuing through to Diapangou, 1983 are 75 (43), 121 (29), 46 (18), and 43 (22), respectively.

[3] Net Revenue = yield gain x grain price (65 and 92 FCFA/kg in 1983 and 1984) minus fertilizer cost (62 and 78 FCFA/kg for 14-23-15, and 60 and 66 FCFA/kg for urea in 1983 and 1984--fertilizer prices are subsidized 40 to 50%). Includes interest rate charge for six months at rate of 15%. 1 U.S. dollar = 381 FCFA in 1983 and 436 FCFA in 1984.

[4] Net Revenue ÷ additional labor of tied ridging and fertilizer application. Manual and donkey traction require 100 and 75 hours of additional labor/ha for tied ridging respectively. Fertilizer application requires 95 additional hours/ha.

Tied ridge construction has the advantage that no cash outlay is required if family labor is utilized. However, a survey of technology adoption by farmers in FSU villages indicated that the number of farmers constructing tied ridges and the hectarage of tied ridge construction outside the trial plots were small--an average of 0.32 hectares/farmer with the largest being 1.0 hectare (Ohm, et al., 1985b). When questioned, farmers indicated that they would like to construct more TR but they did not have sufficient family labor. Hiring from an outside labor pool is limited at the time tied ridges must be constructed because the active labor force of all households is fully occupied with work in their own fields. Linear programming representative farm models (Table 3, column 2) also indicate that labor availability constraints prevent the manual tying of animal traction constructed ridges from being utilized on the entire farm.

Another limitation is that tied ridging does not work well on sandy soils because the ties tend to break down in heavy rain. Nevertheless, an estimated 40% of the presently cultivated land in Burkina and 15% in Mali appears to be suitable for tied ridging. This represents 1.2 million hectares (Burns, 1985). Tied ridges have been shown to be both agronomically and economically feasible as a technology applicable at the present time to increase cereal production in the WASAT. However, the labor constraint requires a search for labor-saving technologies.

Diguettes/dikes. There are various water conservation/erosion methods in addition to tied ridges that are or could be used in the WASAT. The construction of diguettes, although not as effective in retaining water as tied ridges, is a water conservation method that has been investigated. Diguettes are barriers 10 to 15 cm high mainly made of rocks and placed on field contour lines 10 to 50 meters apart. The barriers are permeable and slow rainfall runoff to allow for increased infiltration. They have improved water retention and significantly increased yields in the northern (Yatenga) region of Burkina (Wright, 1985). This technology has the advantage that it can be constructed in off peak labor periods with family labor and is not as labor intensive as tied ridging. However, rocks (the principal material) or other material in some regions are not available to construct the diguettes. Economic analysis indicates that the returns in the first year alone are greater than the labor bill (at the going wage rate) of constructing the diguettes. In Burkina Faso, local government agencies have constructed large dikes and barriers to control water flow at the village level. Although diguettes and other forms of water retention and control require further research, the large dikes and diguettes are technologies that could be used at present.

Complex Chemical Fertilizers. Under on-station and on-farm conditions, significant yield increases for maize, sorghum and millet have been obtained using complex mineral fertilizers (Pieri, 1985; Ohm, et al., 1985b; FSU Annual Reports). Yield response to fertilizer is, however, highly variable between sites and years (Spencer, 1985). Nevertheless, some researchers suggest that continuous cropping using chemical fertilizers is potentially possible in the WASAT (see Pieri, 1985, p. 77 for a literature review

Table 3. Whole farm modeling analysis of tied ridging with donkey traction, Central Plateau, Burkina Faso.

Variable	Traditional Management (donkey)	Tied-Ridging Technology[1] Tied by Hand	Tied with Machine Two Passes	Tied with Machine One Pass
	hectares			
Total Area Cultivated	5.5	5.6	5.6	5.5
Maize				
Traditional	.20	-	-	-
With Tied Ridges	-	.20	.20	.20
Red Sorghum				
Traditional	.60	-	-	-
With Tied Ridges	-	.60	.60	.60
White Sorghum				
Traditional	.80	.51		
With Tied Ridges		.29	.80	.80
Millet				
Traditional	3.18	3.15	3.15	1.84
With Tied Ridges	-	-	.33	1.64
Peanuts	.76	.85	.53	.43
Total Cereals Production	kgs			
Per Household	2103	2436	2651	2737
Per Resident[2]	150	174	189	196
Net Farm Income[3]	000's FCFA			
Per Household	215.3	246.2	253.5	262.2
Per Worker[4]	30.8	35.2	36.2	37.5

[1] Labor times of 75 man hours/ha for tying of the ridges by hand, 20 man hours/ha to machine tie with two passes, and 2 man hours to machine tie with one pass. Yield estimates in kgs/ha for traditional practices and the technical intervention of tied ridging are as follows: maize (1090 to 1730), red sorghum (672 to 940), white sorghum (472 to 660), and millet (320 to 415). 1985 fertilizer and grain prices were used.

[2] Based on 14 residents/household.

[3] Annualized cost of 4,400 FCFA for tied-ridging machine subtracted in columns 3 and 4.

[4] Based on 7 active workers/household.

and references). Decreases in yield and fertilizer efficiency, however, have been observed after two to five years of continuous cropping where organic matter has not been incorporated into the soil (Pieri, 1985).

In Burkina Faso, on-farm researcher-managed trials indicate that the response of maize yields to fertilizer on the relatively high fertility compound soils was not economically profitable (1982 FSU Annual Report, 1983). On-farm farmer-managed trials indicated that fertilizer can be profitable when using fertilizer alone on sorghum (Table 2, column 3). There is, however, considerable risk for the farmer of losing the cash outlay when fertilizer is used alone, as demonstrated by the percentage of farmers who would have lost cash in Table 2, column 3. Both yield and profitability substantially increase, however, when tied ridges and fertilizer are used in combination, as indicated in Table 2, column 4. Also, as shown in column 4, the risk of losing the cash outlay from the purchase of fertilizer substantially decreases when fertilizer and TR are used in combination.[4] Fertilizer in combination with TR for millet on millet land has also been shown to be profitable with only a moderate risk of farmers losing the fertilizer cash outlay (Ohm, et al., 1985a).[5]

A survey of four FSU villages in Burkina indicated a range of fertilizer use on cereals from zero farmers in the sample of the northern village of Bangasse to 33% of the farmers in the southern village sample from Poedogo which has better land and higher rainfall. In the more northern region, fertilizer use is riskier due to lower and more erratic rainfall. Average hectarage fertilized in the villages that used fertilizer ranged from 0.34 ha at Nedogo to 3 ha at Poedogo (Ohm, et al., 1985b).[6] Although the use rate per hectare was not established, field staff indicated it was substantially lower than the 100 kg/ha of 14-23-15 fertilizer applied to most of the FSU trials in the villages.[7]

The evidence to date on fertilizer use in the WASAT suggests that complex fertilizers are a technology that can be used at present but yields are highly variable and the incidence of fertilizer cash outlay loss by farmers is high unless combined with a water retention technique such as TR. The risk of losing cash decreases in the higher soil fertility and higher rainfall areas. Empirical evidence also suggests that fertilizer use or water retention techniques such as TR when used alone can be economically feasible but that when used together, the profitability substantially increases. Moreover, the number of farmers losing cash decreases substantially as compared with the fertilizer only strategy.

Indigenous Rock Phosphate. The benefits of using indigenous rock phosphate deposits in the WASAT are potentially appealling in terms of logistics, transportation cost advantages, and foreign exchange savings. Workable deposits occur in Senegal, Mali, Niger, Togo, Benin, Nigeria, and Burkina Faso. On-station and on-farm trials have however, found the rock phosphate to have solubility problems (IFDC, 1985; Pieri, 1985). The combination of the low P release in a water-soluble form that is readily available for use by plants and the low P-sorption capacity of the WASAT soils have resulted in poor agronomic performance from rock phosphate applications. There is little or no potential for direct application of WASAT rock phosphate with the possible exception of the Mali (Tilemsi) and Niger (Tahoual) deposits (IFDC, 1985).

Two methods are used to increase the agronomic effectiveness of rock phosphate. One method is to highly granulate the rock and the other method is acidulation. Even when highly granulated the agronomic effrectiveness is low and several years of consecutive applications are required before significant yield increases are observed (IFDC, 1985; FSU Annual Reports). After several years of application, benefit-cost ratios were still lower than other sources of phosphorous (IFDC, 1985).

Four years of FSU on-farm farmer-managed trials in Burkina Faso using highly granulated Burkina rock phosphate (100 kg/ha rock phosphate with 50 kg/ha urea applied each year on the same plots) also indicated low benefit-cost ratios. Benefit-cost ratios of less than one with a 50% subsidized rock phosphate price were obtained (Unpublished FSU data). In the same experiment, benefit-cost ratios of 1.3 were obtained from a rock phosphate/ tied ridging treatment but the benefit-cost ratio decreased to 0.69 when unsubsidized prices were used. FSU cooperator farmers did not like using the rock phosphate due to its poor agronomic performance and application problems due to its highly granulated form.

IFDC has developed two processes for the partial acidulation of rock phosphate: Acidulation with sulfuric or phosphoric acid converts the calcium phosphate into a more soluble form. Research on the agronomic effectiveness of partially acidulated rock phosphate in the WASAT has given conflicting results (Batiano, et al., 1985). Inconsistent results were obtained by FSU with 50% acidulated Burkina rock phosphate in a one year on-farm researcher-managed trial with sorghum and millet (Ohm, et al., 1985a). The partially acidulated rock phosphate is also highly granulated giving rise to farmer application problems.

Few economic studies of acidulated rock phosphate are available for the WASAT. When compared with single superphosphate, the relative economic performance of acidulated rock phosphate on millet in Niger is generally lower but is not consistent across sites or years (IFDC, 1985).

To be agronomically and economically feasible, the solubility problems of rock phosphate will have to be overcome. The present effectiveness of acidulation requires further on-farm testing. Once rock phosphate became agronomically and economically feasible, fertilizer plants and distribution networks would require several years to develop. A source of sulfuric or phosphoric acid at economically feasible prices is also required (Pieri, 1985). Thus rock phosphate appears to be a technology most appropriate in the intermediate run, after the technical problems of solubility and application are resolved economically at the farm level.

Animal Manure and Compost. Manure and compost are already being used effectively on fields near the compound although application and composting techniques could be more efficient (Pieri, 1985, Table 11). The principal constraint to the increased use of manuring and composting is their finite supply. Few organic waste materials are left once the household and animal feed requirements are met. Manure availability will increase only when animals are penned to make collection possible. However, cattle are grazed on fallow land away from the living quarters and the labor involved in confined rearing of animals is too great. Cattle are also entrusted to herders because of feed shortages close to the village. As fallow land

declines in the old settlement areas, it will be increasingly difficult to support cattle near the village and in the area in general.

While animal manure and composting are agronomically and economically feasible for use around the compound area at present, they do not represent farm management practices that will substantially increase cereal production in the WASAT in the short and intermediate run because of their finite supply. Their potential will only be realized in the long run when the farming system evolves from the dominant cereal-based system to a more intensive cereal-forage/cash crop system that is able to support more livestock near the village.

Mulch. Crop residue mulch can reduce rainfall runoff and increase water infiltration but sorghum and millet stalks in raw or compost form may add little to soil fertility (Pieri, 1985, p. 91). As with manure, the principal limiting factor of mulch is its finite supply--especially in the northern half of the WASAT. The demand for its uses as animal feed, fuel and construction material leaves most fields bare by planting time and even when it is not all used, the prevalent custom is to burn it. Moreover, crop residues (3 to 5 T/ha.) are not sufficient by themselves to increase soil fertility and water retention capacity appreciably.[8] In addition, applications of mulch (10 T/ha.) can give rise to nitrogen deficiency which can only be overcome by composting or the addition of nitrogen (Pieri, 1985).

Plowing/green manuring. Significant yield increases from on-station and on-farm research have been observed from deep ploughing and tillage practices which change the structure of the soil, allowing better root establishment and improved water infiltration and storage (Nicou and Charreau, 1985; Dugue, 1985). Most tillage in the WASAT is done by shallow, manual cultivation (85% of farmers) or by shallow, animal traction cultivation. Little pre-plant ploughing or tillage is done because of the need to plant soon after a rain (within 2 to 3 days). The soil is generally too hard and the animals too weak at this time of year for effective ploughing to take place before a major rain.

Green manuring can also increase the fertility of the soil and add to its water retention capacity (Pieri, 1985). However, this practice also requires deep ploughing to incorporate the plants into the soil. To be effective, pre-plant and deep ploughing and green manure incorporation all require substantial draft power which can only be given by healthy, well fed double ox teams. This type of draft power will be available only in the long run when the farming systems can support high level-maintenance of the draft animals.

2) Labor Saving Technologies

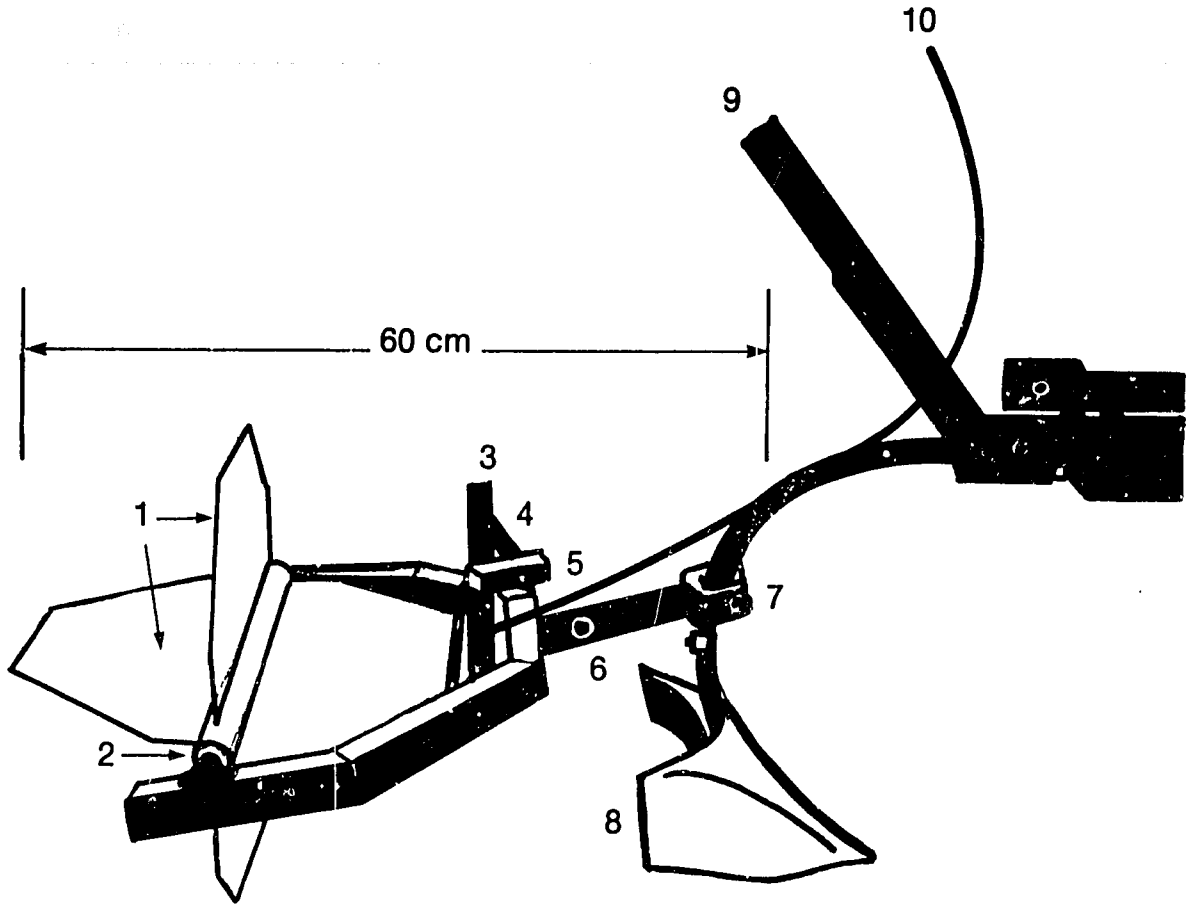
Animal Traction. An estimated fifteen percent of farms in the WASAT use animal traction--mainly for transport, shallow weeding , or shallow land-preparation plowing (Matlon, 1985) (see Photograph 2, page 40). Farmers in general use only one mechanized operation rather than using animal traction for all the agricultural activities of soil preparation, planting and weeding (Jaeger, 1985). To date, animal traction usage in the WASAT can be characterized as land using (extensive). Some studies have reported

significant farm area expansion from animal traction usage. Animal traction can perform weeding 6 to 7 times faster than manual weeding (Jaeger and Sanders, 1985). Increased yield effects have been reported in the literature (mainly from ploughing) but the yield effects are generally small (Binswanger, 1978).

In spite of low animal traction adoption in the WASAT at present, it is a technology that is feasible for use in the short run. Animal traction can be made more economically attractive to farmers. Present internal rates of return can be doubled and tripled by higher utilization rates (Jaeger, 1985). Higher utilization rates can be achieved by increasing the number of mechanized operations. In the past, many animal traction programs have failed in the WASAT because utilization rates were not sufficiently high. Returns to first time users of animal traction in the first years of operation are generally low because learning curves can be as long as five years and is a deterrent to first time users (Jaeger and Sanders, 1985). First time users can obtain the full benefit of mechanization quicker through farmer and animal extension training and an improved market for trained draft animals.

Mechanical Ridge Tier. To respond to the labor constraint in constructing tied ridges, the IITA/SAFGRAD Agronomy Program designed a prototype mechanical ridge tier (MRT) (Figure 6) for animal traction (Wright and Rodriguez, 1985) (see Photographs 7 and 9, pages 41, 42). With FSU and IITA/ SAFGRAD collaboration, the MRT was field tested as part of Burkina's 1985 national farming systems program (Nagy, et al., 1986a). Yield levels compare favorably between ridges constructed with animal traction and tied manually and those ridges made with the MRT. When the two pass method is used (first ridging and then using the MRT) the MRT substantially reduces the labor requirements from an average 75 man hours/ha for the manual tying of animal traction ridges to 20 man hours/ha. The MRT operation requires only 2 to 3 additional hours above ridging alone when ridging and tying with the MRT are done simultaneously (one pass). Donkeys must be strong and healthy for the one pass method. Oxen, which are mainly available on the frontier, clearly have an advantage and can easily do both operations simultaneously.

Linear programming representative farm models indicate that while available labor constrains the tying of ridges manually to 1.1 ha (Table 3, column 2), the MRT can tie 3.2 ha when using the one-pass method (Table 3, column 4) and is highly profitable. The profitability is further increased with the addition of fertilizer (Table 4) although hectarage under tied ridges decreases to 0.9 for manual tying and to 3.0 with the MRT because labor is required for fertilizer application. Budget analysis also indicates the profitability of the MRT under various prices and good/bad year weather scenarios (Nagy, et al., 1986a).



1. Shovels
2. Axel bearing (pipe)
3. Latch lever
4. Rubber band (inner tube strip)
5. Latch adjuster (for correct angle and to compensate for wear in bearings, shovels and latch)
6. Shovel angle adjusting bolt
7. Coupler
8. 30 cm ridger that allows soil to flow over the top
9. Handles of "houe Manga" (FAO donkey weeder)
10. Bicycle cable to brake lever

Figure 6. The IITA/SAFGRAD mechanical ridge tier (donkey version).

Table 4. Whole farm modeling analysis of a tied ridging-fertilization technology combination with donkey traction, Central Plateau, Burkina Faso.

Variable	Traditional Management (donkey)	Tied-Ridging Technology[1]		
		Tied by Hand	Tied with Machine: Two Passes	Tied with Machine: One Pass
	hectares			
Total Area Cultivated	5.5	5.6	5.7	5.6
Maize				
Traditional	.20			
With Tied Ridges		.20	.15	.15
Red Sorghum				
Traditional	.60			
With Tied Ridges		.60	.68	.60
White Sorghum				
Traditional	.80	.70		
With Tied Ridges		.10	.80	.95
Millet				
Traditional	3.18	3.15	3.18	1.88
With Tied Ridges			.05	1.27
Peanuts	.76	.86	.79	.71
Total Cereals Production	kgs			
Per Household	2103	2604	2970	3354
Per Resident[2]	150	186	212	240
Net Farm Income[3]	000's FCFA			
Per Household	215.3	253.2	273.2	296.4
Per Worker[4]	30.8	36.2	39.0	42.3

Source: Nagy et al., 1985.

1 Based on application of 100 kg/ha 14-23-15 fertilizer at planting and 50 kg/ha urea four weeks after planting (20 man hours/ha labor requirement for each application). Labor times of 75 man hours/ha for tying of the ridges by hand, 20 man hours/ha to machine tie with two passes, and 2 man hours/ha to machine tie in one pass. Yield estimates in kgs/ha for traditional practices and the technological interventions of fertilization and tied ridges in combination are as follows: maize - not fertilized (1090 to 1730), red sorghum (672 to 1236), white sorghum (472 to 913) and millet (320 to 660). 1985 fertilizer and grain prices were used.

2 Based on 14 residents/household.

3 Annualized cost of 4,400 FCFA for machine subtracted in columns 3 and 4.

4 Based on 7 active workers/household.

Information from farmer questionnaires and field staff indicates that the major problem with the MRT is its awkwardness. However, most farmers were able to operate the MRT fairly efficiently after 15 to 30 minutes in the field. Several engineering features require redesigning but the overall consensus of the field trials is that the MRT or a machine similar to the MRT can be used at present not only as a labor-saving device but also as a yield-increasing technology.

Herbicides. Herbicides could be used to decrease the labor constraint in the peak-labor-demand, planting/weeding period (Spencer, 1985). At present, acquiring herbicides in the WASAT is difficult and little research has been done to tailor herbicides to WASAT conditions. Both broad leaf and slender leaf plants as well as various trees are grown in association in the same field and these are sensitive to different herbicides.

Economic analysis in northern Nigeria (Ogungbile, 1980) suggests that weeding, either by animal traction or manually, is more profitable than herbicides at present. Herbicides will find an increasing role in the WASAT only when cropping intensities are increased to the point where they require more intensive weeding (Norman, 1982) and when the opportunity cost of labor substantially increases (Ruthenberg, 1980).

3) Improved Varietal Research

Few improved varieties of food crops are used by farmers in the WASAT. Significant yield increases for varietal improvement from on-station research have been observed but a large yield gap between on-station and on-farm yields exists especially for the staple crops of sorghum and millet. Experimental results suggest that the cereal yield gap is less for local than for improved cultivars (Matlon, 1985).[10] Yields from FSU on-farm trials in Burkina for improved maize, red and white sorghum, and cowpeas rarely exceeded the yields of local varieties of the traditional management treatments (FSU Annual Reports).

Analysis by ICRISAT of sorghum and millet cultivars indicate that the on-station selection procedures under a high management environment (high fertility, tillage and water management) have resulted in elite cultivars being more management responsive than local varieties but at the same time inferior at lower management levels (Matlon, 1985). This suggests that breeding objectives should include screening and selection procedures that can provide cultivars which also exploit moderate management levels and that there is a need to hasten the process of variety evaluation onto on-farm trials (Matlon, 1985). With the current selection procedures, the full impact from varietal development will only be felt in the WASAT when farmers utilize a higher degree of improved management practices--practices such as an MRT-fertilizer combination--which would not take place until the intermediate run. Also, even if change occur in the present breeding objectives, leading to the development of new varieties able to exploit moderate management levels, these varieties will only be available in the intermediate run (five to ten years).[11]

4) Crop Associations

Experiment station studies of different crop associations have received increased attention in the WASAT over the past 15 years (Fussell

and Serafini, 1985). Significant aggregate biological yields from intensifying cereal-cowpea associations have been obtained in research station trials (Fussell and Serafini, 1985; Muleba,1985). Increased legume densities, however, are normally accompanied by serious insect infestation problems requiring pesticide spraying. The role that biological nitrogen fixation has played in obtaining the increased aggregate yields in cereal-legume associations in the WASAT is yet to be determined (Fussell and Serifini, 1985). Studies have shown, however, that under WASAT water stress and mineral deficiency conditions, some legumes may contribute to nitrogen losses (Pieri, 1985).

On-farm researcher-managed trials indicate that the most limiting factors in the performance of cereal-cowpea association intensification are soil moisture and fertility (Ohm, et al., 1985a). Under favorable conditions of moisture and fertility, it is profitable to increase cowpea density but under less favorable conditions, the present practice of the farmers seems to be more dependable and profitable (Ohm, et al., 1985a). Under improved management (tied ridges, fertilizer and pesticides), cowpea densities somewhat higher than those currently used by farmers appear to be economically viable (Ohm, et al., 1985a). There are, however, instances where increased cowpea density has decreased sorghum yields (Matlon, 1983).

Socio-economic studies indicate that farmers are primarily concerned with maintaining cereal yields and that modifications in cowpea densities and cultural practices that decrease cereal yield will not be adopted by the farmer (Sawadogo, et al., 1985; Diehl and Sipkens, 1985; Matlon, 1983). Labor data analysis indicates that intensified cereal-cowpea associations substantially increase planting and weeding requirements (Matlon, 1983). Depending on the planting date, intensification can change the distribution of labor demand and reduce the amount of labor required for final weeding because of the cowpea's competition with the weeds. Although returns to labor can be greater under intensification, farmers do cite lower cereal yields and increased labor demands as the prime reasons for not intensifying (Matlon, 1983).

Limited research has been carried out on cropping associations involving trees in the WASAT. Alley cropping--food crops grown in the alley formed by rows of leguminous shrubs or trees--could form one basis for changing traditional shifting cultivation practices (Kang, et al., 1984). Alley cropping does possess many potential advantages such as providing mulch, firewood, biologically fixed nitrogen, animal feed and erosion control. However, it is very management-intensive and has not been thoroughly researched in the WASAT.

Some intensification of cereal and legume crops can take place in the intermediate run once the physical environment is improved, but significant crop intensification, alley cropping, and biological nitrogen fixation would contribute their greatest potential in the long run after farmers first increase their cereal production.

Sequencing of Technologies and Farm Management Practices in the WASAT

With falling cereal yields and the decline of the bush-fallow system in high density population areas, the first necessity is to develop new technology systems to increase cereal yields. Based upon the information of the proposed technologies as to their present agronomic, technical and economic feasibility (Table 1), the overall sequential pattern of technological adoption would be to use the technologies available in the short run to alleviate the soil fertility/water retention constraints, i.e., fertilizer, tied ridges, diguettes and dikes. This would require alleviating the labor constraint in the peak-labor-demand period of planting/weeding through available labor-saving technologies, i.e., animal traction and the MRT.

Once the agronomic environment has been improved, new variety development will be facilitated. The development of these varieties will take time and be available in the intermediate run as compared with the more immediate availability of the tied ridging/fertilization technology combination. Crop association intensification and diversification and other long run technologies and farm management techniques would then be incorporated as they become technically feasible. Thus, the overall sequential pattern of technology adoption can be dichotomized into a) technologies for the present cereal based farming systems and b) technologies and farm management practices for the future (intensified) farming systems.

Technologies for the Present Farming Systems

Production constraints, household endowments, and household decision making characteristics are heterogeneous in the WASAT, leading to differences in the technology requirements and adoption patterns of various households. Thus, the delineation of recommendation domains can aid the targeting of research, extension, and government policy and programs. This section of the chapter first delineates a set of recommendation domains based on production constraints, household characteristics and resource endowments. The technologies available in the short run (Table 1) are then sequenced as to the probable adoption pattern within each recommendation domain.

Recommendation Domains Based on Production Constraints

The labor endowment shortage is homogeneous throughout the WASAT but access to land is not. Old settlement, high-population-density areas exhibit limited to zero fallow rotation due to the limited access to land. In general, land quality and yield in the older settlement areas is lower than on the frontier, which has access to land and utilizes the traditional bush-fallow system. Both intensification and extensification options are available on the frontier whereas only the intensification options are available in the old settlement areas due to the limited access to land. Thus, technology adoption choices are different in the two areas and a delineation can be made on a population density basis as follows:

A. Old settlement/high-population-density areas (i.e., Central Plateau, Burkina Faso).

B. Frontier/low-population-density areas.

Recommendation domains can also be made on an agroclimatic basis. Higher rainfall and relatively higher soil fertility in a general north to south direction within the WASAT vary technology requirements and expected adoption patterns.

Recommendation Domains Based on Household Characteristics and Endowments

Farmers have been found to be mainly risk averse (Binswanger, 1980; Dillon and Scandizzo, 1978). However the risk aversion of farmers within a group may range between high risk aversion and low risk avoidance depending on their initial endowments, i.e., wealth. Theoretically, the risk that a household will assume is positively correlated with household wealth--wealth being largely embodied in livestock holdings (mainly cattle). Wealth can also be considered positively correlated with the ability of a household to invest in purchased inputs or absorb larger losses in a poor rainfall season. Household characteristics are further delineated into the type of traction (manual or animal) presently being used. This leads to the following recommendation domains based on the household characteristics of risk, wealth and type of traction.[12]

I. A high risk averse, low wealth, manual tillage household--may only adopt low risk technologies and has limited ability to buy purchased inputs.[13]

II. A low risk averse, high wealth, animal traction household--chance of technology adoption higher due to the greater ability to buy purchased inputs.

III. A low risk averse, high wealth, manual traction household--chance of technology adoption higher due to greater ability to buy purchased inputs but has not yet made the transition to animal traction.

Six recommendation domains are presented in Table 5 based upon the household characteristics and population density (access to land) typologies described earlier. The recommendation domains are for the 500 to 900 mm annual rainfall regions. The potential sequential adoption patterns of the available technologies in the short run for the present cereal based farming systems--complex fertilizers, tied ridging, animal traction, and the MRT--are presented in Table 5 for each recommendation domain. The sequencing patterns of the technologies for each recommendation domain are based on the previous discussion of farmers' adoption strategies where technologies are adopted singly or in clusters in a logical agronomic and economic sequence. This is discussed for each recommendation domain below:[14]

I.A. High Risk Averse, Central Plateau, Manual Households

With limited access to land, limited ability to buy purchased inputs and high risk aversion, the opportunities for the household in the first stage of technology adoption are to manually construct tied ridges and use other water retention techniques such as diguettes which use available family labor. Linear programming (LP) results indicate that up to 1 hectare could be put in tied ridges manually by the average household, which would increase production and income (Table 3, column 1). Also, survey results indicated that households used tied ridging at FSU village sites and did tied ridging between 1/3 and 1 hectare per household (Ohm, et al., 1985a). Tied ridging is agronomically feasible and economically profitable. For this highly risk averse group, tied ridging is especially attractive because there is no risk of losing a cash outlay with only family labor being utilized for ridging.[15]

The next step in the sequence of technology adoption would involve a cash outlay. Fertilizer is an option on the land in tied ridges, especially in the more southern regions of the WASAT where rainfall is higher. Fertilizer use, although profitable (Table 2, column 4, Nedogo), would be limited by the small hectarage under tied ridges and the tendency of this group of farmers to avoid risks.

Animal traction in combination with the MRT would seem to be the next step in the sequence. This combination is not only labor saving but yield increasing as well. The addition of the MRT to the machinery complement increases the internal rate of return from 10% for animal traction (weeding) alone (Jaeger, 1984) to between 30-40% on the Central Plateau.[16] LP analysis (Table 3, column 4) indicates that the combination of animal traction and the MRT enables the construction of tied ridges on up to 65% of available cereal land on the average or representative farm and increases total cereals production and income above that of traditional practices and

Table 5. Recommendation domains and likely sequential adoption patterns of technologies in the WASAT.

Household Characteristics	Central Plateau[1] A	Frontier[2] B
I. High risk aversion	1. Manual tied ridges-diguettes	1. Animal traction
Low wealth endowment	2. Animal traction-MRT[3]	2. MRT
Manual traction	3. Fertilizer	3. Fertilizer
	4. Improved varieties	4. Improved varieties
II. Low risk aversion	1. Fertilizer	1. MRT
High wealth endowment	2. MRT	2. Fertilizer
Animal traction	3. Improved varieties	3. Improved varieties
III. Low risk aversion	1. Fertilizer	1. Animal traction
High wealth endowment	2. Animal traction	2. MRT
Manual traction	3. MRT	3. Fertilizer
	4. Improved varieties	4. Improved varieties

[1] High density population, limited access to land and, in general, lower quality land than the Frontier.

[2] Low population density, access to land and, in general, higher quality land than the Central Plateau.

[3] MRT = the mechanical ridge tier.

manual tied ridging.[17] With the increase in income, households would then be in a better position to purchase fertilizers. Internal rates of return for an animal traction-MRT-fertilizer combination range from 25-30% and increase production and income over the animal traction-MRT combination (contrast Table 3, column 4 with Table 4, column 4).

I.B. High Risk Averse, Frontier, Manual Households.

Households included in this category could follow the manual tied ridging/diguette regime of Type IA households on maize compound land but may find it as profitable and less labor constraining to maintain the bush-fallow system for sorghum and millet and use animal traction. The present internal rate of return using donkey and ox traction has been estimated to be 31% and 21% respectively for a frontier area but the rates of return can be doubled with increased utilization thus making the technology very profitable (Jaeger, 1984). Next in the sequential adoption pattern would be the use of the MRT. The use of the MRT by households may not be used concurrently with the introduction of animal traction but the incentive for its utilization would increase as population pressure increased and land became more scarce. With internal rates of return of 35-40% for donkey traction and 25-30% for ox traction, mechanical ridge tying at the frontier could be expected.[16] The third step in the sequence would be the addition of fertilizer.

II.A. Low Risk Averse, Central Plateau, Animal Traction Households

Animal traction households exhibiting a lower risk aversion and a greater ability to buy purchased inputs will likely find fertilizer as the best option, particularly in the more southern areas of the WASAT with higher rainfall. The option of using animal traction to extensify is not available because of the limited access to land and thus the next technology in the sequential adoption pattern would be to use animal traction to intensify using the MRT.

II.B. Low Risk Averse, Frontier, Manual Households

As in I.B., the extensification option of using animal traction will continue to dominate until increased population pressure limits access to land, thus making the intensification option of using the MRT more attractive--especially in the northern areas of the WASAT where the rainfall is more limited and erratic. As soil fertility declines, fertilizer will become more profitable.

III.A. Low Risk Averse, Central Plateau, Manual Households

Households in this category are expected to choose fertilizer over manual tying of ridges because they have the ability to purchase it and are less averse to taking risk. Manual tied ridging could also be an option at first, but presented with the opportunity of using an animal traction-MRT combination, households would probably choose the latter.

III.B. Low Risk Averse, Frontier, Manual Tillage Households

Although these households would not be averse to using the land-substituting inputs, a higher payoff is likely to come from extensification using animal traction in the initial stages of technology introduction. As population pressure on the higher quality land increases, increased utilization of the MRT and fertilizer would be expected.

In summary, different sequential adoption patterns exist for the different recommendation domains. Adoption is expected to be more rapid by those in the low risk averse/high wealth categories. Given the present levels of research, extension, and government program support, some groups such as the high risk averse/low wealth old settlement farmers may never adopt any of the technologies.

Tied ridging, chemical fertilizer, and animal traction have all been potentially available to farmers in the WASAT over the last two decades. Yet little adoption of these technologies for cereal production has taken place. Our hypothesis for this lack of adoption is that while the individual technologies may be technically and economically feasible, the economic impact of individual technologies for the level of risk involved has not been sufficiently high. Both farm trials and whole-farm modeling indicate a substantially higher impact from the simultaneous introduction of all three technologies including the MRT. The combined introduction of these technologies alleviates the soil fertility, soil water, and labor constraints and provides a large economic incentive at low levels of risk.

The requirement that the available technologies be introduced simultaneously to satisfy farmers' risk and profit levels before they will be adopted is in conflict with the empirical finding that farmers adopt innovations sequentially. An alternative is to wait until new technologies are developed that satisfy the high profit-low risk criteria so that they will be adopted individually in a sequential manner. Another alternative is to use support programs in view of the pressing nature of the problems in the WASAT. Support programs would have to take into consideration the sequential nature of adoption while trying to achieve total package adoption as quickly as possible. Animal traction farmers may adopt an MRT/fertilizer package simultaneously given high economic incentives and support programs but clearly, for manual farmers (the majority), the combined introduction of animal traction, the MRT, and a fertilizer package all at once in one year is too great.

The main thrust of the support program should be to select the first technology within each recommendation domain (Table 5) and provide economic incentives that make the level of risk of the technology acceptable to farmers. For example, the first technology in the sequence of recommendation domains IB and IIB (Table 5) is animal traction. Support programs

would be required to deal with the pre-conditions for animal traction adoption (as discussed in Chapters IV and V) and provide adequate economic incentives. At a later period when farmers are acquainted with animal traction, support programs would deal with the next technology in the sequence for each recommendation domain. Following this procedure will reduce the adoption time between technologies within the package. The support programs should lead to the adoption of a soil fertility-water retention-labor saving technology package within each recommendation domain. Without support programs, technology adoption of the present technologies available to the WASAT will be very slow with some farmers--in particular the high risk averse/low wealth farmers--not adopting any of the technologies.

Technologies for Future Farming Systems

The long-run goal of technology introduction for future farming systems is to change the upgraded, dominant, cereal-based farming system into a more intensified cereal-forage/livestock-cash crop farming system. Information on the agronomic and economic feasibility of the technologies that may come into play in future farming systems is incomplete, making it impossible to sequence the individual technologies as was done for technologies available for present farming systems.

Improvements in the present cereal-based farming systems will set the stage for a more intensive crop association and rotation regime. Given the yield increase from the fertilizer/tied ridges/improved variety combination, an estimation has been made that moderate cereal surpluses could be expected in the WASAT in the future with the adoption of these technologies (Savadogo, 1986). This would make it possible to shift some production out of cereals and utilize available land, labor and capital on more intensive cereal/forage/cash crop rotations--especially cereal/legume rotations that could provide biological nitrogen fixation and reduce the costs of and dependency upon outside sources of nitrogen.

Feed availability would increase livestock numbers and improve animal traction, not only by better nutrition, but also by shifting to more oxen power and away from the lower draft donkey power that dominates low quality forage farming systems. This would mean better crop residue incorporation and green manuring opportunities. With increased livestock numbers in proximity to the household, more manure would be available. Although farmers would initially adopt these technologies sequentially, the process of adoption would be an iterative one as the more intensive use of one technology allows a more intensive use of another, i.e., increased forage allows more cattle to be kept near the compound resulting in more manure which in turn may allow more forage hectarage.

Footnotes

[1] It would be more appropriate to measure risk in terms of a time series variance (i.e., over many years) as opposed to a cross sectional variance method (i.e., over many farmers in one year) as used here. Three years of data make it difficult to undertake a time series risk analysis. For a textbook treatment of risk analysis, see Anderson, et al., 1977.

[2] Tied ridges (TR) are small depressions made between crop rows either by hand tillage or by a combination of animal traction and hand tillage. When constructed by hand, depressions 32 cm long x 24 cm wide x 16 cm deep, spaced 1-1/2 meters apart are made between the rows. When constructed with animal traction, the fields are first ridged with a cultivator ("houe manga") which is equipped with a middle sweep to create a furrow. This is then followed by hand tillage to make a 16 cm high ridge perpendicular to the furrow every one to two meters. The depressions catch and hold water after a rain and increase water infiltration and retention. Due to the larger water holding capacity of animal traction tied ridges, water retention ability is greater than that of manually tied ridges.

[3] One exception should be noted. Traditionally maize is grown on the relatively higher fertility compound land. Three years of on-farm researcher-managed trials experimenting with maize on non-compound land with TR in general did not show significant yield increases (FSU Annual Report, 1983; Lang, et al., 1984; and Ohm, et al., 1985a). These experiments appear to indicate the need to first utilize organic material or fertilizer to convert the less fertile land into the equivalent of compound land before putting the tied ridges on it if maize is to be grown there.

[4] All the FSU economic analyses have been carried out using subsidized fertilizer prices (40 to 50%). Clearly, the economic profitability would be lower and the incidence of fertilizer cash outlay loss greater utilizing unsubsidized prices.

[5] Trials examining the possibility of growing maize on good sorghum land and sorghum on good millet land by upgrading the soil through a fertilizer/tied ridge combination were also conducted. Three years of on-farm, researcher-managed, maize on sorghum land trials proved inconclusive (FSU Annual Reports) and although a sorghum on millet land experiment showed promise, sorghum plant establishment was a problem (Ohm, et al., 1985a).

[6] The observed farmer adoption rates in different regions correlate well with experimental evidence which suggests that yields are less variable and more responsive to fertilizer and that there is less risk of losing fertilizer cash outlay as rainfall levels and land quality improves.

[7] When questioned, farmers said that they saw the value of fertilizer but that credit and availability were obstacles to greater use. All complex fertilizers are imported from outside the WASAT and usually distribution within each country is handled by a para-statal organization.

[8] An FSU on-farm, farmer-managed experiment involving tied ridges and mulch (5 T/ha.) on maize was conducted in two village sites in Burkina in 1984 (Ohm, et al., 1985a, p. 17). The mulch part of the experiment was abandoned since only 6 of the 50 farmers had access to sufficient mulch.

[9] The MRT is attached to an animal drawn cultivator with one large middle sweep. The MRT is essentially a paddle wheel (45 cm in diameter) with four paddles, one scraping the ground, building up earth, until it is tripped by the operator every 1-1/2 to 2 meters to create the tie in the furrow between the two ridges.

[10] Analysis of five management factors--plowing, tied ridges, fertilization timing, planting arrangement and weeding timing--indicated that the major determinants of the yield gap between the experiment station and farmers' fields were plowing and tied ridges (Matlon, 1985). Also, the major problems observed in the on-farm trials with the elite cultivars are drought and heat stress related, leading to poor seedling establishment and poor flowering and grain filling ability. Spittlebug problems have occurred on the new sorghum variety of Framida (Ohm, et al., 1985b) and striga continues to be a problem with most new sorghum varieties.

[11] The development of hybrid varieties such as the hybrid sorghums bred for the Sudan (Gebisa, 1986) may play a role in obtaining moderate level management response. The poor marketing infrastructures of the WASAT, however, would prevent hybrids from being a technology that could be used in the short run. Present breeding for disease and pest resistance in sorghum and millet is encouraging (Andrews, 1986; Andrews, et al., 1985) and is expected to play an important role in increasing cereal yields in the intermediate run.

[12] Empirical evidence linking reduced risk aversion with higher levels of wealth is not available in the WASAT. It has been a standard part of decision theory that at higher levels of wealth, risk aversion would decrease (Anderson, et al., 1977). This proposition seems to be consistent with field interviews with farmers about their objectives (see Chapter IV, page of this report).

[13] Not included among the categories is a high risk averse, low wealth, animal traction household. While this category undoubtedly exists in the WASAT, the number of households in this category would not be large.

[14] The recommendation domains presented in Table 5 are discussed at the inter-household level which considers resource endowments and decision-making in the context of a family unit vis-a-vis another family unit.

The recommendation domains could also be discussed at the intra-household level which considers differences--in gender, age, and access to and control of resources within the household--which may lead to differences in the sequencing and types of technologies adopted by the various sub-groups (see McKee, 1983; Nagy et al., 1985).

[15] The opportunity cost of labor (wage rate from outside employment) ranges from 30 to 50 FCFA/hr (FSU unpublished survey data). At an opportunity cost of 35 FCFA/hr, farmers would not have lost money by undertaking the construction of tied ridges (Table 2).

[16] Calculations made using the procedure by Jaeger (1984) and adding appropriate costs and revenues based on FSU on-farm farmer-managed trials to estimate the yield increases from the use of the MRT (Ohm, et al., 1985b; Nagy, et al., 1986).

[17] The weekly available labor hour figures used in the model are based on conservative estimates. Increasing the labor availabilities by 10 to 20% for the tied ridging period and/or allowing tied ridging to also take place in the following period results in tied ridges being constructed on all the cereal land.

CHAPTER VI

POLICY IMPLICATIONS AND FUTURE AVENUES FOR RESEARCH AND EXTENSION

This report has proposed that the overall sequence of technology intervention for the WASAT is: 1) technologies that improve the agronomic environment, i.e., water retention and soil fertility improvement: With appropriate policy and institutional support this technology combination can be immediately implemented; 2) the use, when they become available, of improved varieties that can exploit moderate input levels: If varieties are developed for the moderate input levels recommended in 1) above, this technology is expected to be available for farmer adoption in the next five to ten years; and 3) more intensive livestock/cereal systems in the better agricultural areas and a shift back to extensive grazing and forestry in the more marginal agricultural regions. There are many types of technologies for those intensive livestock/cereal/cash crop systems that can now be productively studied on the experiment station and in on-farm trials so that these systems can be available to farmers after the next decade.

The first priority of the agricultural policy, research and extension community in the WASAT is to develop technologies to increase the yields of the cereal-based farming systems which dominate the area. The present focus should be on alleviating the low soil fertility/low soil water retention constraints. Complex fertilizers, the water retention methods of tied ridges, diguettes and dikes, and the labor-saving technologies of animal traction and the mechanical ridge tier are already available for extension in much of the region.

Tied ridging, chemical fertilizer, and animal traction, however, have all been potentially available to farmers in the WASAT for more than two decades. Yet there has been little adoption by WASAT food crop producers of any of these three innovations. This is because there was little economic incentive to adopt these technologies prior to the 1960's because food consumption needs were being met. Moreover, there was little export demand for sorghum and millet. Hence, there was little demand for new cereal technologies. However, with increased population, recent droughts and the deterioration of the soil quality in the higher population regions during the intervening years, the demand for new cereal technology has substantially increased.

Credit, fertilizer, and animal traction non-availability and lack of information have all been cited as reasons for the low level of farmer adoption of the above technologies in the WASAT. From our perspective the principal reason for the failure to adopt these individual components is that the economic impact of each of the three components has not been sufficiently high by itself. Fertilizer utilization is too risky in poor rainfall years without some simultaneous method to increase the availability of water at the critical times of plant development. Tied ridges by themselves do not resolve the low soil fertility problem. Family labor

availability constrains the amount of tied ridging construction. It appears from the on-farm trials and the whole-farm modeling results that all three technologies (including the MRT) would need to be introduced together before economic incentive and risk levels are adequate for technology adoption. Introducing the technologies together would alleviate the soil fertility, soil water and labor constraints and provide high economic incentives at levels of risk that would be attractive to farmers. However, as previously discussed, farmers adopt technologies sequentially and not as a package.

An option is to wait for the research community to develop new technologies that will, individually, provide a sufficient economic incentive at a level of risk that is attractive to farmers. Another option is to develop support programs that will enable farmers to sequentially adopt the available technologies en route to total package adoption. The review of the constraints to cereal production and the review of the available and future technologies for the WASAT (Chapters IV and V) point out that such individual technologies will not be available in the short run and will probably not be available in the intermediate run (10-15 years). The pressing problems of the WASAT require more immediate solutions which can only be brought about by support programs to facilitate the adoption of the available technologies. If the package of available technologies is introduced without special government programs, farmers are expected to adopt the technologies in the sequence given for each recommendation domain as outlined in Chapter V (Table 5). Adoption by recommendation domain would vary, with those in the low risk averse/high wealth categories adopting the technologies first. Some groups such as the high risk averse/low wealth old settlement farmers may never adopt any of the technologies.

Implementation of a support program to increase the present cereal production in the WASAT would include:

a) credit programs for the cash outlays required by farmers for fertilizer and animal traction;

b) farm management information, especially on efficient utilization of animal traction and fertilizer, from the extension service;

c) development of the input and product markets.

A main thrust of the support program would be to select the technologies within each recommendation domain that farmers would most likely adopt first (as described in Table 5) and provide the economic incentives and pre-conditions for farmers to adopt the technology. Once farmers become acquainted with the technology, the next technology would be supported in a similar manner and so on until the total technology package was adopted. Appropriate economic incentives and pre-conditions would ensure that technology adoption proceeded as quickly as possible so that all the farmers could adopt the total package in the shortest possible time.

To facilitate new-technology introduction, some of the potential types of research and extension institutional support programs are mentioned below.

Priorities for Extension and Local Governments

The highest priorities for extension and local government agencies involve focusing on the soil fertility/water retention technologies of manual tied ridging, diguettes and dikes, complex fertilizers, animal traction and the mechanical ridge tier. These technologies should be put forward on demonstration fields (using local farmer participation where appropriate) individually and as packages for each of the recommendation domains.

There is a role for local government agencies in the construction and maintenance of large dikes and barriers to regulate the speed of rainfall runoff at the village level. Within each region, individual households would either construct tied ridges and/or diguettes--whichever is the most appropriate for the area. Where diguettes are used, assistance from local government agencies may be required for correct contour placement.

A critical role will have to be undertaken by extension agencies to ensure that the appropriate preconditions exist for animal traction adoption. The preconditions of shorter learning curves for both the farmer and draft animals and higher utilization rates can be facilitated by animal traction programs. Extension agencies could be involved in training farmers (technical operation and animal maintenance) and in the training of draft animals until a draft animal market develops. Shortening the learning curve will itself increase utilization rates which can be further increased by an appropriate complement of implements including the mechanical ridge tier.

Priorities for On-Farm Testing

The prototype IITA mechanical ridge tier requires further modifications at the engineering level to reduce its weight and awkwardness and increase its adaptability for hook-up with a wide range of cultivator/plow equipment (Nagy, et al., 1986a). Other possibilities include an automatic tripping device and even new design concepts, which need to be rigorously field tested with farmer participation. As modifications and new design concepts are developed, they must be made available to the extension system and local manufacturers and provisions made for information feedback to the on-farm testing agencies. The mechanical ridge tier is an implement that can be made locally and every attempt by the local extension agencies to provide prototype copies to local manufacturers should be undertaken. Locally-made mechanical ridge tiers enable location-specific adaptations arising from a local manufacturer/farmer interchange.

Priorities also include further on-farm testing of diguettes and of modifications of diguettes and barriers. Further on-farm testing across the WASAT of raw and acidulated rock phosphate from all the major rock

phosphate deposits in the WASAT is required to evaluate the agronomic and economic feasibility of this technology.

Priorities for Experimental Research Stations

On-station crop improvement programs require a change in the present emphasis on screening and selection under high management conditions--management conditions much higher than can be provided by WASAT farmers in the intermediate run. Thus, crop improvement programs in the WASAT should concentrate on developing varieties that show stability over time and exhibit a response curve that exploits moderate management levels. Selection must be focused on resistance to important pests and diseases as well as production superiority under varying levels of soil productivity and available soil moisture--all of which contribute to production stability. This change in crop development goals requires new screening and selection procedures and an increased interdisciplinary effort between on-station and on-farm research.

The designing of labor-saving devices for fertilizer application, planting and other field operations should be further studied for both manual and animal traction farmers where applicable. Research on water retention methods other than tied ridges or diguettes is required for those areas where these two technologies are not effective especially on the sandier soils characterizing much of the Sahelo-Sudanian zone.

CHAPTER VII

SUMMARY

Whole-farm modeling was critical in identifying the potential effect of new technologies and in evaluating the seasonal labor bottleneck. As on-farm trials produce more technologies that pass the yield and profit criteria, whole farm modeling analysis will become increasingly important to identify the interactions of technology components and estimate their potential impact at the farm level.

A major contribution of the Purdue farming systems research project was not the identification of the individual constraints but rather a study of their interconnected nature. It is necessary for farming systems research projects to concentrate on the well-known synergistic nature of agricultural inputs and not be satisfied with minimum cost input changes, which also have minimal effects on yields or profits.

The seasonal labor constraint has been stressed as the principal barrier to agricultural development in the WASAT and in other semi-arid areas in Africa. However, a more agronomic orientation to the analysis of the water requirement and soil fertility problems was necessary. The combined effect of improved water retention, increases in soil fertility, and overcoming the seasonal labor bottleneck with the mechanical tied ridger had a substantial impact on farm income. Since the combined effects are much larger than the individual effects, it is unfortunate that farmers tend to adopt one input at a time. Governmental support of the combined practices appears to be necessary to facilitate their combined introduction.

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APPENDIX 1

Administrative Report

In December 1978, Purdue University was awarded a two year contract with the U.S. Agency for International Development to establish and operate a farming systems research unit in Burkina Faso, as one of the components of the Semi-Arid Food Grain Research and Development Program (SAFGRAD).

This contract, AFR-C-1472, had several mandates:

1. Analyze small farm conditions and application of new technologies to those conditions.

2. Formulate strategies regarding development and application of small farm relevant technology;

3. Develop recommendations regarding physical research priorities, and;

4. Design, help organize and analyze farmer field trials and studies as a means of performing the above.

After several extensions, the contract was amended in 1985 to reflect an additional set of objectives:

1. Complete the transfer of the farming systems research methodology and techniques gained under this contract to national research organizations in the SAFGRAD countries.

2. Finalize analysis of empirical research results;

3. Finalize and publish guidelines for the methodological analytical, or organizational and operational conduct of FSR in the SAFGRAD region.

4. In conjunction with the SAFGRAD coordination office, complete the groundwork for a West African regional FSR network.

The termination of the project occurred on June 30, 1986. Field activities in Burkina Faso were maintained through March 31, 1986.

The body of this report provides a description of the achievements of the project in terms of its mandate. This section is the administrative report covering the implementation of this contrast.

Contractor staff were provided logistic support by USAID in accordance with local AID procedures; this included housing and utilities, furniture, household equipment and medical facilities to our long term staff. In addition, two vehicles, were provided to our team for the duration of the project. These vehicles were financed outside our contract but from SAFGRAD project funds.

Initially, the Purdue University team, comprising an agricultural economist, agronomist and rural sociologist were to be provided office

space at the Kamboinse Research station, outside the city limits of Ouagadougou. At the onset, the FSU office was established in Ouagadougou then moved to Kamboinse; however, because the vehicles provided were not very reliable and transportation problems for local hire staff created major problems, the office was relocated in Ouagadougou in agreement with SAFGRAD and USAID. The FSU team continued to closely work with the ICRISAT and IITA teams who had responsibility for other research components of the SAFGRAD program.

At Purdue University, a steering committee composed of the departments heads of Agronomy, Agricultural Economics and Sociology/Anthropology was established to guide activities of the FSU. It frequently met to evaluate progress, discuss issues relevant to the project, and to formulate overall strategy for achieving project objectives.

Technical coordination and backstopping for the project was maintained on the Purdue campus during the entire project period. Dr. Wilford H. Morris provided this service from 1978 to June 1983 and Dr. John H. Sanders from July 1983 to termination. On-campus administrative and logistic support was provided by the Office of International Programs in Agriculture under the directorship of T. Kelley White and D. Woods Thomas. Other administrative staff responsible for project activities were Dr. James L. Collom, associate director, OIPIA, and Mrs. Katy Ibrahim, administrative assistant for the FSU project.

In addition, Dr. Thomas was a participant of the SAFGRAD Technical Advisory Committee (TAC) and Consultative Committee (CC) of the SAFGRAD which met yearly in Burkina Faso. These committees were a channel for review of all SAFGRAD activities in West/Central Africa.

During the seven and a half years the FSU project existed, a total of nine long-term staff were on site in Burkina Faso for a total of 225 person months (P/M):

Paul Christensen, agronomist, acting chief-of-party, February 1979 to December 1981 - 33 P/M;

Richard Swanson, rural sociologist, October 1979 to July 1983 - 46 P/M;

Ram Singh, economist and chief of party, April 1979 to March 1981 - 24 P/M;

William Jaeger, economist/computer analyst, December 1981 to June 1983 - 19 P/M;

Ronald Cantrell, agronomist/chief of party, February 1982 to January 1984 - 23 P/M;

Mahlon Lang, economist, February 1982 to April 1984 - 26 P/M;

Herbert Ohm, agronomist/chief of party, August 1983 to August 1985 - 24 P/M;

Christopher Pardy, economist/computer analyst, December 1983 to June 1983 - 16 P/M;

Joseph Nagy, economist/chief of party, July 1984 to April 1985 - 14 P/M;

In addition, several short-term technical staff and consultants traveled to Burkina Faso for a total of 18.5 P/M. They are as follows:

In 1979, Kenneth Jones, computer specialist at Purdue, spent .50 P/M to assist our in-country staff in organizing the data management. That same year, Ms. Annie Buryer, a sociologist, spent 3 months in the field, assisting our rural sociologist in setting up the village questionnaires. In 1980, Herbert Butler, rural sociologist, spent .50 P/M assisting in the analysis of the collected research data. In 1981, Stan Cohen, computer specialist and agricultural economist, spent 4 P/M in the analysis of socio-economic data. Len Malczynski, computer specialist, also spent .75 P/M in the field in organizing the data handling systems. Anne-Marie Kaylen, M.S. candidate in the Department of Agricultural Economics, spent eight 1/PM in the field to collect data for her thesis.

Wilford H. Morris, technical coordinator for the FSU, spent 2.00 P/M in the field to provide support to our in-country team.

In 1983 Jon Brandt, agricultural economist, spent .50 P/M in Burkina Faso to assist Kimseyinga Sawadogo in the collection of data for his Ph.D. Thesis. In 1984 Charles Rhykerd, agronomist and soil specialist, spent .75 P/M working with our staff in collecting soil samples and providing agronomic support to our staff. John Sanders, as on-campus technical coordinator, spent a total of 1.00 P/M in the field working with the field economists.

Purdue administrative staff also traveled to Burkina Faso during the existence of this project for a total of 4.5 person months:

	P/M
T. Kelley White, acting director, IPA	.50
Paul Farris, Head, Agricultural Economics Dept.	.25
D. Woods Thomas, Director, IPIA	1.50
Katy Ibrahim, Administrative Assistant, FSU	1.00
John Sanders, Technical Coordinator	.75
James L. Collom, Associate Director, IPIA	.50

Purdue University also conducted an internal evaluation of project activities in Burkina Faso in 1984. Members of the team who spent one week in-country were:

Bernard Liska, Dean, School of Agriculture
William Dobson, Head, Agricultural Economics Department
Marvin Phillips, Head, Agronomy Department
D. Woods Thomas, Director and Associate Dean, International Programs in Agriculture

Sawadogo Sibiri participated in the On-Farm Experimentation Workshop, University of Harare, Zimbabwe (co-sponsored with CIMMYT), February 6-24,

1984; the East Africa Agricultural Economics Program, CIMMYT; Nairobi, Kenya, October 27 to November 6; and in the evaluation of FSR programs with ACPO's in Senegal, February 24 to March 1.

Three Burkinabe staff enrolled at Purdue University for additional long-term training:

Paul Compaore, Agricultural Economics, M.S., 1983-1985
Baya Toe, Agricultural Economics, M.S., 1983-1985
Kimseyinga Savadogo, Agricultural Economics, Ph.D., 1979-1986

All have returned to Burkina Faso; Dr. Savadogo as a professor at the University of Ouagadougou. Paul Compaore and Baya Toe are working in the Burkinabe Ministry of Agriculture.

All of these educational activities contributed significantly to quality and dependable data collection and team spirit. In addition, these training activities were a significant factor in the transfer of host country technical and research staff to the national agricultural research program, IBRAZ.

Training for U.S. graduate students was also made possible through this project. Ms. Anne-Marie Kaylen spent eight months in the field collecting data for her M.S. thesis in agricultural economics. Also, three graduate students funded under the Purdue/INTSORMIL project spent eight months each in Burkina Faso, working with our staff in support of the project, while collecting data for their field research. These were Michael Roth, Ph.D., Kimseyinga Savadogo, Ph.D.; and Ann Bukowski, M.S. Under FSU auspices, William Jaeger developed his Ph.D. dissertation on the economics of animal traction in Burkina Faso.

The Farming Systems Unit project cooperated in the conduct of two regional workshops. In September 1983, in cooperation with ICRISAT and IRAT, a regional workshop on farmers' participation in the development and evaluation of technology was held in Ouagadougou. The proceedings of this workshop were published by the International Develpoment Research Centre. In April 1985, the FSU, in conjunction with the SAFGRAD Coordination Office, conducted a workshop on technologies appropriate for farmers in semi-arid West Africa. The proceedings of this workshop (in English and French) were distributed widely by the Office of International Programs in Agriculture.

Thirty-six research-based technical papers were written and distributed under FSU auspices. (See Appendix 2 for a listing of these publications.)

The Farming Systems Unit project was not without administrative and/or logistical problems. Included were such things as unavoidable delays in transfer of funds to the field, inadequacy of in-country transportation arrangements; imperfection in project design; establishing FSU relationship with national agricultural institutions and international development assistance organizations; internal and international political events; and the lack of ex-ante long-term contractual and funding commitments. Excellent cooperation among the U.S., national, regional and international organizations involved in the program made it possible to resolve such issues with minimal impact on project productivity.

Purdue University is deeply grateful to the OAU/STRC, the SAFGRAD and its Consultative and Technical Advisory Committees, USAID/Ouagadougou, AID/Washington, the government of Burkina Faso, ICRISAT, IITA, and other entities for their assistance and cooperation in the conduct of this project. Without such, the objectives of this ambitious research could not have been attained.

APPENDIX 2

Publications List

1. FSU/SAFGRAD Staff, "Questionnaire Utilises pour le Etudes Sur les Systems de Production Agricoles Dans Des Villages Echantillons de Haute Volta"; Farming Systems Unit Project, International Programs in Agriculture, Purdue University, West Lafayette, Indiana; January 1980.

2. Saunders, M. O., "Farming Systems Research Unit Working papers: (1) Agriculture in Upper Volta: The Institutional Framework; (2) Local Ecology, Population, and Ethnic Groups in Upper Volta, and (3) The Mossi Farming Systems in Upper Volta," International Programs in Agriculture, Purdue University, West Lafayette, Indiana; 1980.

3. Bruyer, A., "Towards a Use of Survey Materials, Report on Zone of Zorgho," Farming Systems Unit Project, International Programs in Agriculture, Purdue University, West Lafayette, Indiana; May 1980.

4. Christensen, P. J., "Observations on the Major Classification of Field Trials Used in Farming Systems Research," Farming Systems Unit Project, International Programs in Agriculture, Purdue University, West Lafayette, Indiana; January 1981.

5. Christensen, P. J., "Rock Phosphate Fertilizer in Upper Volta, Part 1. Preliminary Report on Policy Implications of Cereal Yield Characteristics," Farming Systems Unit Project, International Programs in Agriculture, Purdue University, West Lafayette, Indiana; April 1981.

6. Christensen, P. J. and R. A. Swanson, "SAFGRAD/FSU 1981 Research Programs," Farming Systems Unit Project, International Programs in Agriculture, Purdue University, West Lafayette, Indiana; April 1981.

7. Cohen, S., "Costs and Returns of Household Crop Production, Nedogo, Upper Volta," Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, September 1982.

8. Lang, M., R. Cantrell, and J. H. Sanders, "Identifying Constraints and Evaluating New Techology in the Purdue Farming Systems Project in Upper Volta," in C. B. Flora (ed.), Animals in the Farming System, Kansas State University, Manhattan, Kansas, pp. 184-206, 1984.

9. Jaeger, W. K., "Animal Traction and Resource Productivity: Evidence from Upper Volta," in C. B. Flora (ed.), Animals in the Farming System, ibid., pp. 431-460, 1984.

10. Singh, R. D., E. W. Kehrberg, and W. H. M. Morris, Small Farm Production Systems in Upper Volta: Descriptive and Productive Function Analysis, Experiment Station Bulletin, Purdue University, West Lafayette, Indiana, 1984.

11. Lang, M. G. and M. Roth, "Risk Perceptions and Risk Management by Farmers in Burkina Faso," Paper presented at the Annual Farming Systems Conference at Kansas State University in 1984.

12. Rhykerd, C. L., "Constraints and Research Needs for Livestock Production in Upper Volta," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1984.

13. Sanders, J. H., "The Evolution of Farming Systems Research: Towards Where?", International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1984.

14. Roth, M. and J. H. Sanders, "An Economic Evaluation of Agricultural Technologies and Implications for Development Strategies in Burkina Faso," International Programs in Agriculture, Purdue University, West Lafayette, Indiana. First presented at the Annual Farming Systems Conference at Kansas State University in 1984.

15. Lang, M. G. and R. C. Cantrell, "Accenting the Farmers' Role: Purdue Farming Systems Unit," in P. Matlon, R. Cantrell, D. King and M. Benoit-Cattin (edited), Coming Full Circle, Farmers' Participation in the Development of Technology, International Development Research Center, Ottawa, Canada, pp. 63-70, 1984.

16. Lang, M., H. Ohm, and R. Cantrell, "Adaptability Analysis of Farmer-Managed Trials in Farming Systems Research," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1985.

17. Lang, M. G., "Agricultural Production and Marketing Activities of Women in Burkina Faso," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1985.

18. Lang, M. G., "Crop and Livestock Marketing Patterns in Burkina Faso," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1985.

19. Pardy, C. R., "Cereal Sales Behavior Among Farm Households in Four Villages in Burkina Faso," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1985.

20. Nagy, J. G. and H. W. Ohm, "Economic Analysis of Tied Ridges and Fertilization in Farmer-Managed Sorghum Trials in Burkina Faso," Paper presented at the International Conference of Agricultural Economists, Malaga, Spain, 1985.

21. Nagy, J. G., L. L. Ames and H. W. Ohm, "Tecchnology Evaluation, Policy Change, and Farmer Adoption in Burkina Faso," Paper presented at the Farming Systems Symposium, Kansas State University, Manhattan, Kansas, 1985.

22. Schaber, L., "A Literature Review of Soil Fertility in the West Africa Semi-Arid Tropics (WASAT)," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1985.

23. Sanders, J. H., J. G. Nagy, and B. Shapiro, "Developing and Evaluating New Agricultural Technology for the Sahel: A Case Study in Burkina Faso," Submitted to Economic Development and Cultural Change, 1985.

24. Ohm, H. W. and J. G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa, International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1985, 359 pages (also available in French).

25. Roth, M., P. Abbott, J. Sanders, and L. McKinzie, "An Application of Whole-Farm Modelling to New Technology Evaluation, Central Mossi Plateau, Burkina Faso," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1986.

26. Diallo, N. N. and J. G. Nagy, "Burkina Faso: Access and Control of Resources in the Farming Systems: Recent Legal, Political and Socio-Economic Changes," Paper presented at the Conference on Gender Issues in Farming Systems Research and Extension, Gainesville, Florida, February 1986.

27. Nagy, J. G. and L. L. Ames, "Evaluation of New Technologies in Burkina Faso Using Whole Farm Modelling," Paper presented at the Annual Conference of American Agricultural Economists, Reno, Nevada, 1986.

28. Sanders, J. H. and B. Shapiro, "Agricultural Technology Development in Burkina Faso," in Chapter 12 of Y. Moses (ed.), Proceedings, African Agricultural Developpent Conference: Technology, Ecology, and Society, California State Polytechnic Institute, Pomona, California, 1986.

29. Nagy, J. G., H. W. Ohm, L. L. Ames, and L. D. Schaber, "Analysis of IITA/SAFGRAD Mechanical Ridge Tier," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1986.

30. Nagy, J. G., H. W. Ohm, and S. Sawadogo, "Burkina Faso: A Case Study of the Purdue University/SAFGRAD Farming Systems Project," forthcoming in the Florida Farming Systems Project Case Studies Series, 1986.

31. Ames, L. L., "A Preliminary Report on the Evaluation of New Technologies in Burkina Faso," International Programs in Agriculture, Purdue University, West Lafayette, Indiana, 1986.

32. Annual Report, (English), 1979.

33. Annual Report, (English), 1980.

34. Annual Report, (English), 1982.

35. Annual Report, (English & French), 1983.

36. Annual Report, (English & French), 1984.

37. Annual Report, (English), 1985.

38. End of Project Report, 1986.

Theses List

1. Kaylen, A. M., "Current Farming Conditions in Nedogo and Digre, Upper Volta," M.S. Thesis, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, August 1982.

2. Jaeger, W. K., "Agricultural Mechanization: The Economics of Animal Traction in Burkina Faso," Stanford University, unpublished Ph.D. thesis, 1984. To be published as a book by Westview Press.

3. Bukowski, A.S., "Performance of Grain Markets in Selected Areas of Burkina Faso," M.S. Thesis, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, May 1986. Utilized some of the data and research support from the FSU project in Upper Volta but was directly supported by INTSORMIL.

4. Roth, M., "An Econoimc Evaluation of Agricultural Policy in Burkina Faso, West Africa: A Sectoral Modeling Approach," unpublished Ph.D. dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, May 1986. Utilized some of the data and research support from the FSU project in Upper Volta but was directly supported by INTSORMIL.

5. Savadogo, K., "An Analysis of the Economic and Socio-Demographic Determinants of Household Food Consumption in Ouagadougou, Burkina Faso," unpublished Ph.D. dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, 1986.