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# COMPLETION REPORT:

# ECONOMIC COMPONENT

# TECNOLOGY FOR SOIL MOISTURE MANAGEMENT

# (TSMM/ECONOMICS)

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# COMPLETION REPORT (DRAFT)

# ECONOMIC COMPONENT of the TSMM Project

## I. Introduction

The purpose of this report is to summarize the basic features and findings of the Economic Component of the Technology for Soil Moisture Management Project (TSMM/ECONOMICS). The period of time covered is from October 1, 1986 to September 30, 1991, ie., from point of origin of the economics work to completion.

In this report the problem context of the Project, its objectives, organization and research framework, tasks carried out, principal findings, and outputs produced are covered.

## II. Project Background

### A. Problem Context

On a worldwide basis rainfed agricultural production systems make up about 82 percent of total cultivated area. Irrigated land accounts for the other 18 percent. Within the total rainfed area, arid and semi-arid regions comprise almost 67 percent of the world's agricultural land. In all, 59 percent of these drylands are found in developing countries. In 27 developing countries located in the Near East, Africa and Asia low rainfall areas make up from 75 to 100 percent of the land area.

Total population in the dryland areas today is close to 850 million, and growing at a rate of about 2.5 percent per year. This growth rate, among the highest in the world, means that the current population will double in less than 30 years. In many dryland countries food production for the past decade or more has not kept up with population growth with the result that per capita food production has declined. Thus, the combination of high population growth and reduced productivity has detrimentally affected the well-being of large numbers of rural inhabitants and city dwellers dependent on agriculture. It has also set in motion a trend of increasingly intensive cultivation leading to serious negative impacts on the environment. Arising from this situation is growing uncertainty regarding the long-run sustainability of dryland farming.

Low rainfall agricultural areas are, therefore, extensive, involve significant numbers of people and face serious difficulties which are expected to get worse over time. Due to high cost and special management requirements the potential for either area expansion or gains in productivity within irrigation schemes is low. Consequently, the kind of changes needed are those that must take place in, and result in greater productivity of, the dryland sectors of the developing world.

The fundamental issue is how to stimulate rapid diffusion of basic soil, water, and related crop and livestock management practices that can enhance and sustain farm income, food consumption and the long-run productive capacity of the natural resource base upon which so many depend.

Unfortunately, the development and maintenance of sustainable agricultural production systems in dryland areas is difficult. These areas are characterized by: erratic as well as limited rainfall; high year-round temperatures and solar radiation; low soil water holding capacity; surface soil hardening; soil compaction; low infiltration rates and consequent excessive water runoff and erosion; wind erosion; shallow soils; stony soils; soil toxicities; and low soil fertility due to low organic content. Farming technology is usually very simple with minimum safeguards for the protection of scarce water supplies and fragile soils. Overall, productivity in these areas is only one-fourth to one-half that of comparable agroclimatic conditions in developed countries. Moreover, as indicated, the long-run trend in fertility given current farming practices is downward.

Improved management of soil and water resources can increase farm productivity, and at the same time decrease land degradation. In many locations improvements can be achieved by more widespread application of known principles of soil and water management to crop and livestock production. In other situations new concepts and methodologies especially tailored to some of the unique aspects of third-world drylands are required.

Government policies, land tenure arrangements, and social, cultural, and economic factors also influence the way in which dryland resources are utilized. Achieving long-term sustained growth in the productive capacity of low rainfall areas will require sound decisions based on accurate assessments of resource problems and potentials and on careful analysis of alternative policies, programs and projects.

NEED TO ADD PARAGRAPH TO CONTINUE THOUGHT OF LAST SENTENCE TO SAY SOMETHING ABOUT SPECIAL PROBLEMS OF DRYLAND AREAS -- VARIABILITY, UNCERTAINTY, NEED FOR LONG-TERM STRATEGIES AS WELL AS IMMEDIATE RESPONSE CAPABILITIES FOR PLANNERS. THE SAME ISSUES BECOME THE PROBLEMS TO WHICH RESEARCHERS MUST RESPOND, AND BE ABLE TO RESPOND WITH BETTER METHODS AND DATA. HENCE, UNDERSTANDING OF DRYLAND PROBLEMS OR CONTEXT, ANALYTICAL METHODOLOGIES AND DATA SYSTEMS, COMPUTATIONAL TOOLS AND INFORMATION PRODUCTS ARE CRUCIALLY IMPORTANT FOR DEALING WITH THE LARGE AREA, THE MANY PEOPLE AND THE DIFFICULT ENVIRONMENT.

### B. TSMM Project Overall Objectives

Today, the broad food and agriculture goals of the Agency for International Development are to improve the economic and nutritional status of the poor, and to protect and enhance the quality of natural resources throughout the developing world.

The Technology for Soil Moisture Management Project (TSMM) focusses on the realization of those benefits for the millions of people and the vast area of the dryland agricultural regions of LDCs.

Within this context the developmental objective of TSMM has been to assist developing countries and donor agencies assess soil moisture and related soil fertility problems and identify strategies for increasing the long-term productivity of dryland areas. In recent years the sustainability of farming systems has become a popular issue and Project management has sought to underline the important contribution the Project can make in helping LDCs improve farm incomes and food consumption and maintain or enhance the natural resource base in agriculture.

As means of reaching Project objectives TSMM activities seek to: (1) increase knowledge and understanding of the critical relationship that exists between social and economic factors, the use and management of natural resources, and the achievement of development goals within dryland farming systems; and (2) assist developing countries identify specific soil, water, crop and livestock management strategies needed if income, consumption and sustainability goals are to in fact materialize.

These "means" reflect several important considerations. First of all, is the implied need for research and analysis to expand the current information base pertaining to agricultural production systems, technologies and related resource management practices, socio-economic factors, and the tremendous potential that exists for improvement in the dryland rainfed areas. Second, is the need to rapidly extend this type of information to LDC governments, national and international research organizations, and USAID missions overseas. This last need, in turn, implies the necessity of having an effective program in place by which new information can be disseminated and shared among development practitioners, planners and researchers.

### C. TSMM/ECONOMICS Project Objectives

The program of work carried out within TSMM/ECONOMICS (TSMM/EC) is derived from overall Project objectives and the means chosen to reach those objectives.

Within this framework the specific goals of TSMM/EC have been to: (1) enhance knowledge and understanding of socio-economic relationships which influence the way soil and water resources are managed in dryland agricultural production systems; (2) improve the methodology for farming systems analyses of soil, water and related crop and livestock technologies to incorporate in a better way multidisciplinary concepts; (3) evaluate various technologies and farm management strategies in terms of their socio-economic and resource implications, and (4) augment the network of scientists working on dryland agricultural development issues.

Based upon these goals, TSMM/EC planned outputs have been:

(1) multidisciplinary analytical methodologies that effectively integrate soils, agronomic, agroclimatic and economic data for accurate assessment of improved soil, water, crop and livestock production practices;

(2) automated data and information systems necessary to support comprehensive assessment of resource management options;

(3) computerized analytical systems formatted and documented for use by scientists as well as by general users.

(4) case studies and other analyses of alternative agricultural production technologies and related farm management practices to determine impacts at the farm, community, region and national level;

(5) evaluation public policy and program options for stimulating rapid adoption and diffusion of improved dryland production practices;

(6) scientist to scientist research networks for self-generating improvement in dryland soil and water resource management expertise;

(7) a cadre of dryland soil and water resource management experts highly qualified and available to carry out technical assistance functions;

The day to day activities of the staff assigned to the TSMM/EC component of the Project have all focussed on production of these outputs. Naturally, a division of labor based on available resources and qualified staff has taken place and not all phases of the overall plan of work have received equal attention. Also, achievement of stated objectives and production of outputs involves a hierarchical process wherein completion of one phase is dependent on other accomplishments. Complex case studies, for example, require sophisticated analytical tools which first begin as more simple techniques and then are improved.

In the balance of this report the way in which TSMM/EC is organized, the general design of the research program, and the current status of the many tasks undertaken over the course of the project leading to project outputs is summarized.

### D. TSMM/ECONOMICS Project Organization

The TSMM Project is implemented through a USDA/AID PASA (Participating Agency Service Agreement). The Economic Research Service (ERS) of USDA and the Agricultural Research Service (ARS) of USDA are the implementing Agencies. ERS is responsible for activities dealing with socio-economic aspects of the Project. Dr. John C. Day of the Resources and Technology Division of ERS, (RTD), is the TSMM/EC coordinator and principal scientist.

TSMM/EC began operations in Fiscal Year 1986 on the basis of a long-term scope of work submitted to and approved by AID. Each year annual plans of work and supporting budget are provided to the AID Project Manager, Dr. Raymond E. Meyer, for his approval. ERS/RTD is then solely responsible for achieving the objectives specified in each operating plan. Plans have been adjusted to reflect changing needs.

In order to assemble a critical mass of highly dedicated development specialists and research experts, the TSMM/EC coordinator has tapped into the Title XII, U.S. Land Grant University System through use of USDA Cooperative Research Agreements. Purdue University, West Lafayette, Indiana and Washington State University, Pullman, Washington are the institutions collaborating ERS under the Cooperative Research Agreement mechanism. Principal Investigators have been Dr. Robert R. Deuson, Purdue and Dr. Walter. R. Butcher, Washington State.

Other institutions with whom informal interactions have taken place are Michigan State University, Texas A & M, Texas Tech, University of Arizona, University of Hawaii, University of Florida, University of Illinois, and Kansas State University, In addition, TSMM/EC has emphasized the importance of strong multidisciplinarity and has actively sought out informal collaboration with soil scientists and agronomists within ARS and other institutions. Outside the USDA/Landgrant system productive interaction and joint activities have taken place with national and international research centers worldwide, and universities overseas.

The program of work within TSMM/EC is truly collaborative and highly coordinated. Research plans developed at the core institutions, ie., Purdue, Washington State, and ERS, are jointly developed by the principal investigators at each location. Planning meetings and Project reviews are held regularly. Complementarities are fully exploited, staff are often shared to capture special expertise needed by another, data, information, models, etc., are exchanged. Joint authorship of publications is frequent. Thus, the TSMM/EC program has multiplied the effectiveness of the resources provided by capitalizing on synergism made possible by willing cooperation among core Project staff. TSMM/EC average annual funding level (FY-1986-90) is $190.5 K.

## E. TSMM/ECONOMICS General Research Framework

Early-on planning for ERS participation in the ongoing TSMM Project determined that because of scale limits there should be a geographic focus to the work responsive to the very serious problems confronting the people of Sub-Sahara Africa, particularly the Sahel, and those in parts of the Middle East. As a result, a research and analysis program was put together giving priority attention to West Africa (a summer rainfall area) and a winter rainfall mediterranean climate. Interest in extension of results between these climatic zones and from these regions worldwide were an important consideration, however, individual countries and/or sub-regions was to be the initial perspective. Opportunities for interaction with USAID mission were criteria for country selection. Purdue University and Washington State University were selected as core collaborators because of expertise in, and involvement with in-place bilateral AID projects within, the respective priority geographic locations.

It was also felt that the "farming system" nature of the soil and water management problem called for holistic, or whole-farm, analytical approaches, hence, TSMM/EC has stressed the development and use of whole-farm modelling techniques in its work. Moreover, the nature of the problem means that reasonably accurate representations of such things as soil conditions, weather, cultivar characteristics, plant growth processes, farm calendars, all as they might be expected at the farm level, viz., the point where final resource use decisions are made, are necessary in economic analyses of improved technologies. Given the lack of this kind of information representative of dryland farming in the priority geographic areas TSMM/EC has put a fair amount of effort on the adaptation and use of plant-growth models and soil-water balance models to compensate for the scarce physical data. Since the TSMM Project budget was never sufficiently large to permit primary data collection (ie., farm surveys, field trials, experimental plots) reliance on secondary data and/or primary data made available to us through collaboration with other projects was necessary.

TSMM/EC has given weight to the need to institutionalize new information and techniques of analysis in the development process and has, therefor, given special attention to capturing and disseminating experiences gained through reports and publications, automated and documented data bases, and documentation of analytical models developed. In the case of raw primary data held by collaborators TSMM/EC was often able to provide support for processing, analysis, and documentation all of which might not otherwise have occurred.

The general framework describing TSMM/EC efforts to date is, therefor:

1. A geographic focus on areas of serious human welfare issues
2. Development and testing of improved analytical tools for technology appraisal at the farm level
3. Case studies
4. Data base development and documentation
5. Model documentation
6. Information dissemination

The principal tasks undertaken within this framework are summarized in the following section.

## III. Principal Tasks Undertaken in TSMM/ECONOMICS

## A. Adaptation of Crop Growth and Soil Water Balance Models for Economic Analysis

Crop growth simulation models are being increasingly used to predict crop yields for different cultivars, various cultivation and management practices and a range of soil and weather conditions. Soil-water balance models are often sub-components of crop modelling systems, but they may also serve as useful stand-alone approaches for predicting the impact of soil and water management practices on crop yield. Models in use range from simple one or two variable functions, spreadsheets, to extremely large and complex models of hour by hour plant growth based on plant physiology.

Crop growth models and soil-water balance models, properly calibrated to fit local conditions, can be particularly useful for estimating crop yield response to alternative production practices in situations where actual response data is unavailable; however, for some approaches data requirements and computer capacity can be prohibitive.

TSMM/Economics researchers are working with a number of scientists to adapt practical crop growth and soil-water balance models to critical problem situations, thus generating basic agronomic data required for economic analyses of new farm production technologies. As indicated, TSMM is concerned with the dryland farming areas of the developing world, focussing our attention on the semi-arid and arid zones. In these particular locations agronomic data is in short supply and large and complex models are of limited practical use. We have, therefore, stressed the need to put together simple, less data demanding, approaches that can generate accurate information in a reasonable length of time. Our progress to date in this effort is reflected in the following tasks completed and in-process. How this phase of our work is integrated with our economic farm models to form the analytical base for a series of case studies pertaining to soil, water and crop management issues in Africa and the Middle East is brought out in a later section of the report.

**1. An empirically based soil water balance/crop-yield response model.**

**2. A simulation model of millet and cowpea intercrop.**

**3. A linear response and plateau model of crop response to fertilizer and other inputs.**

**4. Adaptation of EPIC barley model to barley, vetch and medic farming systems in Northern Jordan.**

**5. Computer-based linkage system for weather/crop/livestock whole-farm models.**

**The Soil Water Balance/Crop-Yield Response Model.** From secondary sources of information J. Day adapted a soil water balance model incorporating crop yield-moisture stress relationships to crops, soils, and agroclimatic conditions of West Africa. Five plant growth stages are utilized in the model, viz., establishment, vegetative, flowering, yield formation and ripening. These stages correspond to different water demand phases during plant growth. Parameters reflecting rainfall infiltration by time periods during the growing season, water holding capacity in the root zone and deep percolation are included which can be calibrated for different soils. This side of the model is a water supply component. Crop yield reductions due to moisture stress during plant growth stages (imbalances between soil water supply and plant water demand) are calculated for different crop, weather, management practices and calendars of operation. The effect on yields of improved soil and water conservation practices and farm planning can be ascertained. The soil-water balance/crop response model is operated through a LOTUS 123 spreadsheet and imported to a system of various whole-farm economic models. Application has been in the form of a series of farm level case studies for Mali in which a number of improved technologies and farm management strategies were examined in a typical dryland farming context.

The soil-water balance/crop response model provides useful first approximations of crop yields whenever field or experimental data is missing.

**The Simulation Model of Millet and Cowpea Intercrop.** This model, developed by J. Lowenberg-DeBoer, M. Krause, R. Deuson and K. Reddy, is based on the generic GROWIT crop growth model. First, GROWIT was calibrated for these two particular crops and then modified to take into account their interaction including the competition for available sunlight. The soil water budget is calculated assuming that both crops draw from a common soil water resource. Four plant growth stages are used in both the millet and cowpea sub-models (germination, vegetative growth, flowering, and grain fill). A computerized spreadsheet (LOTUS 1-2-3) was developed to facilitate model design, testing, and application. The individual millet and cowpea components of the model were calibrated with data from the ICRISAT Sahelian Center in Sadore, Niger, and with on-farm trial data collected by National Institute for Agricultural Research in Niger (INRAN) researchers in the Maradi region of Niger. The intercrop model was calibrated using on-farm trial data taken in Maiguero, Niger from the 1986 and 1987 crop seasons. The intercrop model was then validated with on-farm trial data from Maiguero (1985) and Rigial Oubandawaki (1987). A regression of the observed crop yields on simulated yields revealed that at the 95 percent level of confidence a zero intercept and a slope coefficient of 1 was obtainable indicating close correspondence between model estimations and actual data.

**The Linear Response and Plateau Model.** The Linear Response and Plateau (LRP) model offers an alternative to crop growth simulation when the information needed to apply simulation techniques is not available. It is based on sound agronomic principles, and is a good tool for providing fertilizer recommendations. The model was estimated by fitting linear splines to yield response data to various phosphorus fertilizers

of varying solubility. The data produced at the ICRISAT Sahelian Center in Sadoré (Western Niger) were provided by the International Fertilizer Development Center. This type of response function can be used to define production possibilities in an LP of farming in Western Niger.

**The Jordan EPIC (Erosion Productivity Impact Calculator) Crop Growth Model.** TSMM/EC research involving the development and use of crop-growth models has included an effort to incorporate the EPIC model (Erosion Productivity Impact Calculator) into our work. The EPIC general model simulates eight major physical/biological components of the plant growth process: hydrology; weather; erosion; plant nutrients; plant growth; soil temperature; and plant environment control. An EPIC model, therefore, simulates crop biomass production (grain and straw) and fertility loss with different crop rotations, cultural practices, tillage techniques, residue management regimes and fertilizer levels.

Our initial undertaking has been to utilize the EPIC system in an analysis we are carrying out in the Ramtha and Mafraq areas of North Jordan. Dr. Abdullah Jaradat, Agronomist, Jordan University of Science and Technology, is collaborating with our staff at Washington State University on the study.

The EPIC model was originally built for conditions and cropping systems encountered in the United States. Dr. Jaradat has adapted a version of EPIC to the crops and environmental conditions of this area using experimental and farm trial data. His model was further modified to fit the cropping systems and farm production practices to be examined in our study. Improvements included in Jordan-EPIC are increased sensitivity to moisture stress and to phosphorous stress as well as more reasonable response to phosphorous fertilizer. Other innovations in Jordan-EPIC are the introduction of vetch, the calibration of barley crop growth parameters for conditions found in Jordan, and the inclusion of a barley-weedy fallow rotation. With this version yield estimates are possible for continuous barley, barley-fallow, and barley-vetch rotations both with conventional and minimum tillage practices. Yield estimates are also possible for conditions of residue incorporation into the soil or residue removal from the field, and for various fertilizer options. A vetch-barley rotation, use of minimum tillage, extensive use of chemical fertilizers, and residue incorporation are all largely untried in Jordan, but are potentially crop yield enhancing and soil/moisture conserving techniques. Zero fertilizer is use is also an environmentally relevant option to consider.

The current version of Jordan EPIC provides sufficiently accurate crop yield predictions for use in economic studies. EPIC Jordan provides a tool for analyzing the profitability, risk and long-run resource use implications of current and innovative agricultural practices in Jordan.

The JARADAT/TSMM version of EPIC represents a fairly complex crop-growth/water-balance modelling scheme. Experience gained in working with this simulation system and incorporating it with our whole-farm models of typical farms in North Jordan will improve our ability to adapt and apply it to other locations. Detailed

information concerning the construction and use of the EPIC Jordan model can be found in EPIC-JORDAN: A Crop Simulation Model Used for Analyzing Agricultural Production in the Mafraq Area of Jordan. (Walter Penaranda and David W. Hughes).

The Jordan whole farm model and the Jordan EPIC model provide prototype frameworks for examining mixed crop livestock farming systems found throughout the Middle East and North Africa.

**The Computer-Based Linkage System.** The EPIC modeling system also includes a weather generator and subroutines for simulating crop growth over a long series of weather years. We have developed procedures for translating these outputs into estimates of parameters for crop yield probability functions. Probability distributions and rainfall-yield functions have been estimated for EPIC-generated barley grain and forage yields under several alternative cropping systems and management approaches. These distributions have been used for direct assessments of technological alternatives and identification of dominated practices. A LOTUS 123 spreadsheet has been developed for converting expected values for yields and farm production input requirements into a linear programming input file in MPSX format.

### B. Whole-farm Modeling

The objective behind the whole-farm modelling efforts of TSMM/Economics is to develop and utilize methodologies for technology assessments that take into account as much as possible the interaction of soils, weather, farm resource base, farm family characteristics, farm production practices and the particular economic setting in which technology adoption and diffusion takes place, viz., the farm site. Information at this level about the impacts of new practices is necessary in order to determine technical and financial feasibility. Similarly, information on the farm level effects of developmental programs and policies and associated economic consequences is important for planning and decision-making.

Our farm modelling work, therefore, is designed to shed light on the farm-level changes in income, food consumption, natural resource use, and farm production practices that might be expected with technology transfer. In our thinking, analysis of policy and program actions that could simulate beneficial technology adoption and diffusion would then follow.

Major tasks completed or underway include development of a number of different computer-based mathematical models of representative farming systems in West Africa, North Africa and the Middle East, viz.,.

**1. A linear programming model of a typical rainfed farming system in the semi-arid region of western Mali (800-1000 mm of rainfall, 120-150 day growing season).**

2. A discrete stochastic programming model based on a typical millet-cowpea intercrop farm model for the Sahelian agro-climatic zone in the Maradi region of Niger (400-600 mm of rainfall, 60-100 day growing season).

3. A Target MOTAD linear programming model to assess sorghum technology for a typical rainfed plus supplemental irrigation farm in Southern Niger (300-500 mm of rainfall, 60-100 day growing season). The model is outfitted with two Expert Systems to facilitate its operation in a user-friendly mode.

4. A dynamic programming intertemporal model of farm-level fertilizer decision-making in the Sahelian agroclimatic zone.

5. A mixed integer whole-farm programming model of a representative barley-legume-livestock rainfed farm in Northern Jordan (300 mm of rainfall).

6. A System of Linear Programming Models of Representative Traditional Farms in Northern Cameroon (600-1200 mm of rainfall, 120-180 day growing season)

7. A Linear Programming Model of Representative Crop-Livestock Traditional Farming Systems in Northern Cameroon (600-1200 mm of rainfall, 120 180 day growing season)

8. A Quadratic Risk Programming Model of a Typical Representative Farm in Northern Cameroon (600-1200 mm of rainfall, 120-180 day growing season)

9. A Model of a Representative Farming System in Northern Benin.

Basic characteristics of each of these models is now summarized.

**The Mali Whole-Farm Linear Programming Model.** TSMM farm modelling efforts began with the development of a very simple linear programming representation of a typical subsistence oriented rainfed farm located in western Mali. This model reflected basic crop production activities of a traditional farm where tillage, cultivation, and harvesting operations are all done by hand. The simple model allows for the possibility of marketing any surplus harvest; however, in actuality almost all production by farms of this type is required to satisfy farm family food needs. The impact of soil erosion on farm productivity was not taken into account in this initial model, nor were specific soil and water conservation practices included as options. A separate soil-water balance/crop response model (see a-1 above) was used, however, to import changes in crop yield associated with changes in rainfall infiltration and soil moisture.

The basic framework by which technological improvements and related farm management practices were to be evaluated was established in the first Mali model. As work progressed various features were added. At this point in time the "Mali model" can be used to evaluate a wide range of farming options, viz., soil moisture conservation, erosion control, short-season and long-season cultivars, alternative planting dates, animal traction and use of chemical fertilizers. Also, more than one rainfall scenario can be examined in any one analysis. For example, the profit maximizing farm plan if a rainfall season capable of producing average yields occur can be identified, as can the plan insuring food for home consumption if instead a worst-case season producing only poor yields were to happen. This feature implicitly takes into account the risk associated with weather and how best farmers may cope.

The Mali model provides a prototype framework which can be adapted to various other locations in West Africa, North Africa and the Middle East.

**The Niger Discrete Stochastic Programming Model.** The Niger DSP model has a slightly different focus than the set of Mali models described above. While assessment of soil, water and crop management options within the small farm subsector is still the basic issue of concern, the DSP model has an added feature. This model is designed to address simultaneously the joint problem of technological change, the use of credit and the effect of risk. Thus, the model deals with the interaction between technology adoption, the amount of credit available to poor farmers, the terms at which they must borrow and risk sharing.

The model uses Discrete Stochastic Programming to incorporates choices by the farmer of crop mix, production practices, and the amount of credit he will seek. The model maximizes expected-utility over a two-year time frame. Expected utility is a function of the wealth generated by alternative production plans, different rainfall states of nature, the probability of each state of nature occurring, and the farmers' aversion to risk. A two-year cycle of production activities, consumption, and cash transactions is embedded in the model in order to consider the dynamic effects of crop yield and revenue outcomes in one year on decision-making in the following year, and to allow for changes in liquidity from year-to-year. In addition to permitting analysis of technology and weather scenarios, the model is structured in such a way that it allows one to examine alternative ways of spreading the risk of dryland farming among different participants in the farm production process.

Procedures have been developed in the Niger DSP for interfacing the Lowenberg-DeBoer et al. simulation model of intercropped millet and cowpea (see Activity B-2 above).

**The Niger Target MOTAD Linear Programming Model.** The second model is a representative farm model for Konni, in Southern Niger. It is a Target MOTAD version of a linear programming model. This type of model incorporates risk analysis by not averaging out the five years of available data but instead, by penalizing the farmer for choosing a technology which, although profit-maximizing in the long-run, may be associated with more risk than the farm household is willing to take in anyone year, or

fails to meet the minimum consumption for that year. This work has met three objectives: (1) to estimate the cost of producing hybrid sorghum seed in Niger using economic engineering principles; (2) to determine the profitability and identify the constraints to farm-level adoption of the different sorghums; and (3) to determine the effect of various government policies, consumer preferences, and farm resource endowments on the adoption of new cultivars. This model is outfitted with two experimental Expert Systems: a front-end system to help the user upload the data and set the parameters of the LP model and a back-end system to help the user interpret the LP results.

**The Niger Dynamic Programming Fertilizer Model.** The dynamic programming model of fertilizer decision-making was developed to analyze the choices available to farmers in Niger if phosphorus sources of various solubility were made available through the development of a national fertilizer industry. This work makes use of a linear crop response and plateau analytical approach (LRP) in a programming framework. It is a partial model of the Nigerien farm in which availability of liquidity is modeled as this may be an important constraint to fertilizer use. The farmer's problem is to choose a soil fertility management strategy in light of alternative investment opportunities available, and that will allow him to continue farming in the Nigerien environment.

**Jordan Barley Cropping Region Mixed Integer Whole Farm Programming Model.** Another geographic area of concentration is the winter rainfall-summer fallow farming location of Northern Jordan. where an analysis of a typical farming operation in the Ramtha-Mafraq locale is underway. The Jordan farm model is designed to deal primarily with land use questions in the context of a very low rainfall situation and a mixed crop-animal small farm production system.

The model is designed to study farmer adoption of productivity enhancing and resource conserving technology, along with nutritionally improved feeding regimes for the farm sheep flock. Emphasis is also placed on optimal allocation of barley crop grains and straw. The model is designed based on farm survey and other data taken from the Mafraq (barley cropping) region of Jordan.

A typical farm in the Mafraq area has 18 hectares of crop land available for crop production. An additional 20 hectares of steppe land and nonarable farmland is assumed to be available for grazing livestock flocks in the spring and summer. One hundred and twenty-one man-days of farm family labor are available during the harvest period. Additional labor can be hired at a rate of 2 JD (Jordan Dinar) per man-day. Farmers can choose between the crop rotations of continuous barley, barley alternated with a weedy (grazed) fallow, and barley alternated with vetch hay. Farm production practices include minimum tillage, conventional tillage, use of chemical fertilizer or using no fertilizer, and either removing virtually all crop residue from the field or allowing a portion of crop biomass to be incorporated into the soil. Jordan-EPIC, a version of the Erosion Productivity Impact Calculator (EPIC) crop growth model, is used to estimate expected crop production under differing weather conditions for all crop rotations under each of the various farm practices. Harvested grain and straw may be feed to livestock

immediately, stored for feeding at a later date or be sold. Crops may also be grazed in lieu of harvest either by the farm flock or rented-out for grazing to migratory herdsmen. Likewise, crop aftermath may also be grazed by the farm flock or rented-out for grazing. Crop aftermath grazing is precluded when crop residue is incorporated into the soil.

Sheep production is included in the model at low, medium, or high quality feeding regimes. Feed requirements (crude protein, energy and bulk) also differ during four feeding seasons. Feeding regimes affect lambing rates, milk production, and quantity and quality of wool production. Available feed sources include grazing land in spring and summer, harvested grain and straw, grain production grazed in lieu of harvest in the summer, grazed crop aftermath, and purchased barley straw, barley grain and wheat bran. Salable outputs from the flock are lambs, cull ewes, cheese, and wool. Replacement ewes can either come from the flock itself or can be purchased.

**The Northern Cameroon System of Linear Programming Farm Models.** The initial effort to model small farming operations in Cameroon first focussed on developing a linear programming model of a representative traditional farm located in a low rainfall regime. Next, this base model was modified to include a set of improved farm production practices applicable to that regime and farming system as recommended by the Cameroon Extension Service. These practices, while judged to be suitable on technical grounds, are not widely utilized by local farmers. Third, both the base traditional model and the extension improvements model were further modified to include additional and/or alternative improvements as developed by the Semi-arid Food Grain Research and Development project (SAFGRAD) of Cameroon. Thus, this Cameroon farm modeling work has resulted in a system of four consistent models that range from depiction of current traditional practices to three different levels of improvements, viz., traditional plus extension recommendations, traditional plus extension and SAFGRAD recommendations, and traditional plus SAFGRAD recommendations only. The system, therefore, permits one to compare optimal farm production plans under various technology options.

In the base traditional farming system model activities are grouped into three categories: crop production, crop selling, and labor hiring. Production activities include land clearing, soil preparation, planting weeding, ridging, harvesting and transporting traditional varieties cultivated either as sole crops or intercropped at different time periods depending on the onset of rains. One to six planting dates are possible, and fallowing is permitted. Crops included are: red sorghum, white sorghum, groundnut, maize, cotton, and muskwari (end-of-season transplanted cowpea) with associations of red sorghum with white sorghum, groundnut, maize, and cowpea, groundnut - maize, and maize - cowpea. The model includes animal power (ox team), five land categories, a family food safety constraint, and long-season crop varieties with little use of N and P fertilizers.

Extension Service recommendations are based on the need to improve soil fertility, utilize crop cultivars better adapted to weather variability, and alter basic cultural practices. The base programming model was therefore modified to reflect new and improved production options dealing with land preparation, cultivar selection, seeding

rate, planting time and density, plant thinning, chemical treatments and fertilization. SAFGRAD research findings indicate that a number of other short-season varieties, planting dates, plant and crop densities, fertilizer levels (of N, P, and P, insecticide use, ploughing and ridging offer potential. These additional technical options were then formulated as programming activities and both the base and the "extension" models were adjusted accordingly.

**The Northern Cameroon Crop-Livestock Farming System Linear Programming Model.** A important issue in the context of West African development is the extent to which livestock can contribute. In order to shed more light on this question, TSMM/EC collaborators at Purdue University examined the relationship between traditional farming methods supplemented with improved practices and livestock operations. The analytical approach followed drew on the representative Cameroon farm models just described, but expanded that modelling effort to include on-farm sheep, goats, and cattle activities. The result is a new representative linear programming farm model designed to evaluate the profitability and sustainability of integrating livestock into crop-based farming systems of Northern Cameroon.

The integrated crop-livestock model has three main components: activities relating to the crop subsector; activities relating to the livestock subsector; and, dynamic relationships capturing the interaction between farm activities and linking the two subsectors. The model, therefore, treats the whole farm as a single system for both crop and livestock production. Model solutions identify the most profitable mix of crops and livestock subject to various farm level constraints and the technology set included.

Since typical farms in the study area are made up principally of those concentrating on either cotton or maize, the integrated model is actually made up of eight versions based on principal crop, farm size, and whether livestock are included or not, viz., small and medium sized cotton-based farms with and without integrated livestock, and the same for maize-based farms. Crop technologies in each case are the traditional set and the SAFGRAD improvements identified in the previous case study. The new livestock activities relate to cattle rearing, small ruminant rearing, buying and selling, grazing on crop residue, stall feeding on purchased feed and/or stored crop residues, and purchase of animal inputs such as salt, vitamins, and mineral supplements. Crop/livestock linkages reflect sources and uses of animal feed, draught power, manure, land, labor, and cash. A twelve-month livestock calendar of operations is included, as are special labor demands for animal upkeep and maintenance, eg., stall feeding, gathering and storing feed, and draught animal training. The integrated model is, therefore, capable of dealing with crop/livestock competition for resources, and identifying the optimal combination of improved crop practices as well as the number and type of animal for the farmer to keep and sell.

**The Northern Cameroon Quadratic Risk Programming Model.**

(Model description to be completed)

**The Northern Benin Representative Farm Model**

(Model description to be completed)

## C. Development of Procedures for Handling Risk, Uncertainty and the Dynamics of Long-term Impacts of Soil and Water Technology Transfer

As has been pointed out above, one of the chief characteristics of the environment in which rainfed agriculture is carried out is variability in the timing and amount of rainfall. This variability, occurring from year to year as well as within growing seasons, creats a risky situation for farmers. When rainfall can't be predicted with great accuracy farmers are uncertain as to their best course of action regarding farm production decisions. Moreover, actions taken in any one year, such as tillage practices, crop rotations and conservation investments, will have implications for soil and water productivity, farm output and farm income in the future. It is for these reasons that the procedures followed in technology appraisals must accommodate risk, uncertainty and the long-term dynamics of resource use. TSMM/EC researchers have addressed the problem of appropriate methodology in a systematic way through the following tasks.

1. **Review of literature on approaches for handling risk and uncertainty in farm technology and resource management decisions.**

2. **Evaluation and comparison of procedures appropriate to rainfed farming systems analysis.**

3. **Identification of operational approaches for incorporating risk and uncertainty into whole-farm planning for West Africa.**

4. **Development of procedures for incorporating intertemporal impacts of soil erosion, reduced fertility and conservation practices in static farm models.**

5. **Development of an optimal control model for evaluating intertemporal dynamic relationships between soil and water conservation practices and productivity.**

6. **Development of a simulation methodology (Soil Erosion Control Under Risky Environment) to evaluate physical and economic impacts of soil and water resource management under uncertainty.**

**The Review of Risk and Uncertainty Literature.** A review of relevant literature dealing with alternative approaches to risk modeling by E. Loehman and R. Deuson (PU) brought to light some of the ways in which risk and uncertainty have been handled in farm programming models. At this point in time, principal conclusions drawn from this review relate to three areas of model design: (1) specification of objective function, (2) the

basis for formulation of risk parameters, and (3) the range of technological choices for risk management.

With respect to objective functions, most models employ an approximation of expected utility, eg., the mean and variance of some outcome such as profit, instead of the complete distribution of that outcome. Moreover, given historical limitations on computer capacity, linear approximations of variance were used. With improvements in computational capacity it is now possible to take into account higher moments, such as skewness, to which risk averse farmers will react. Also, traditional approaches have not allowed placing weights on different aspects of the distribution of outcomes. Here, the need to be able to attach more weight on losses below the mean than above it become important. The use of historical data on yield variations to specify ranges of outcomes and, hence, risk parameters, is not appropriate for modelling of new technologies which are designed to modify yields and variability. Similarly, historical price and yield covariences would not accurately reflect the effects of new technology and government policy. Last, the technological choices in most models has been too narrow when it comes to risk management alternatives, eg., models have not included grain storage options and have ignored the crop-cattle interaction where animals act as a form of stored nutrition for later consumption or sale.

Recommendations stemming from this literature review are as follows:

1. In future work Target MOTAD or goal programming is prefered because these approaches seem most flexible in terms of describing farmer behavior with respect to risk. Behavioral studies can be drawn upon to set appropriate targets and weights on various outcomes. TSMM should consider enlarging the scale of its work to include primary data collection on these special data needs relating to soil and water management technologies and their impacts on variability and risk.

2. Future work should consider how to describe price and yield risk separately, and how to determine price risk from market conditions. Attention needs to be given to the question of how, in this framework, to model production risk using crop growth simulation models.

3. Future work should give more emphasis to the need to consider the time dimension in the farm models, and, related to this, the need to introduce grain storage, either on farm or local, as a risk management option.

**Identification of Operational Approaches for Incorporating Risk and Uncertainty into Whole-farm Planning for West Africa.** The review of risk literature and related recommendations summarized above led to the risk sensitive farm model developed and tested using Cameroon data (Section III., Part D., page 20). In this model new technologies tested included improved varieties of maize, sorghum, and cowpea. Alternative levels of fertilizer were also included. Alternative planting dates were additional farm management options for coping with adverse weather. To describe yield risk, yield models incorporating weather parameters and the effects of different crop production technologies were combined in a whole-farm model utilizing an expected utility objective

function. The probability of a range of weather conditions, a key aspect of this modelling effort, was obtained from historical weather data. Farm input-output information was obtained from farm surveys, farm fields and experimental trials. Thus, technology appraisal was carried out in terms of the distribution of effects. Mean effects and variance can then be related to both weather and to differences brought about by farmers themselves. Mean and variance effects due to economic changes causing price fluctuations were not examined. The implications of expanded livestock operations at the farm level as a means of dealing with weather and crop productivity were evaluated in a linear-programming, ie., non-risk model, as a first step in putting together a "risk" analysis of an integrated crop-livestock system.

**Procedures for Incorporating Intertemporal Effects in Static Models.** The simplest way of modeling whole-farm production and resource allocation decisions is through the use of a static, single-period time frame. Usually the time-frame is based on a crop production cycle or growing year. Static models may be linear or non-linear. Several single-period models may be linked together to cover more than one cycle through recursive programming methods. Whatever specific modeling approach is followed there is still a need to take into account effects, such as soil erosion, loss of soil fertility and increased water conservation, that arise in one year and continue long into the future. Accordingly, procedures have been developed for estimating the present value of future productivity lost due to the effects of erosion and land degradation under given farming practices. We have included these values in our whole-farm analyses of resource conservation in Mali. In one case, an analysis involved the comparison of economically optimal farm plans with and without consideration of the opportunity cost of lost future production.

**The Optimal Control Model.** In addition to the efforts outlined above to establish the basis for explicit consideration of risk, uncertainty and risk aversion in our whole farm modelling, and for handling intertemporal impacts of soil and water conservation within a static framework, we have also sought to "push our analytical frontier" outward into more sophisticated modeling realms. Jeff Krautkraemer's work takes us a long way in this direction. His optimal control models not only embody a long-run time frame in the resource allocation decision problem, but two state variables as well -- soil fertility and soil moisture. As this advanced approach is further tested and data needs clarified we will know more about its practical application in Africa and elsewhere.

**The Simulation of Resource Conservation.** A simulation methodology of the short- and long-run effects of resource management was further developed and refined by P. Setia (USDA/ERS). This methodology (Soil Erosion Control Under Risky Environments -- SECURE) produces estimates of the physical and economic consequences of selected measures designed to achieve targeted levels of soil and water conservation. The analysis takes into account the effects of soil and water conservation on farm income and family consumption under conditions of uncertainty. The information generated is useful for the design of effective public soil and water conservation programs.

In this framework evaluations are carried out in a step-wise fashion involving two levels of analysis: i) technical analysis; and ii) policy-decision analysis. The technical analysis draws upon data pertaining to site specific characteristics such as soils, crop growth and yields, weather, farm production technology, conservation measures, farm operating costs, etc., to produce estimates of net returns, soil loss, variance-covariance of net returns and soil loss for each conservation management system. A conservation management system refers to a combination of crop rotation, tillage method, and control practice. The policy-decision analysis is conducted in two phases. In the first phase, selected management systems are ranked and compared by using profit maximization, expected utility maximization, and safety-first decision criteria to account for farmers' perception of risk and their attitudes. How the risk attitudes of a farmer may influence the selection of a management system can be identified in this phase. Also, the robustness of a management system can be evaluated by different decision criteria. For example, if a system which is consistently ranked highest by each of the selected decision criteria is incorporated in the implementation strategies may enhance the effectiveness of a conservation policy/program.

A whole-farm programming model is employed in the second phase to identify economically optimal combinations of conservation management systems for the farm unit as a whole. The programming model combines the technical information on selected management systems with the farm level resources such as land, labor, capital, tenure, family consumption, etc. and policy variables (soil loss taxes, conservation subsidies and/or cost shares, regulations, etc.). This phase provides the opportunity to examine the feasibility of various policy options, alone or in any combination, to succeed given the current farm resources. It can also be identified if policies to alter the resource or farm organization need to be initiated as well. The methodology has been tested for a representative situation in West Africa.

### D. Data Base Development

An important aspect of TSMM/EC's program of work has been to organize the information with which we work into an automated data base. At this point in time, our data base consists primarily of technical information pertaining to the soils, weather, agronomic practices, and farm characteristics in the rainfed areas of Niger, Mali, Cameroon, Benin, Syria and Jordan. Consistently organized and accessible by personal computers, such a data base is useful for bringing together data from a number of sources for our own immediate research studies, but also for work directly in support of USAID missions in the field. TSMM/EC's budget has never supported collection of primary data. We, therefore, must draw upon secondary data sources and primary data already collected, or to be collected, by collaborating institutions. In the case of the latter source, our efforts to categorize, organize and automate raw data files has been of benefit to our collaborators. TSMM data includes the following:

1. **Niger Experimental and Farm Trials. Collaborators - Purdue University and the National Institute for Agricultural Research in Niger (INRAN).**

2. **North Jordan Farm Surveys. Collaborators - Washington State University and the International Center for Research in the Dry Areas (ICARDA).**

3. **Northern Jordan Field Trials. Collaborators - Washington State University, Jordan University of Science and Technology (JUST) and ICARDA.**

4. **The Niger Dryland - Irrigated Farms Data Base. Collaborators - Purdue University, the European Fund for Economic Development (FED) and the National Office of Irrigated Perimeters (ONAHA).**

5. **North Cameroon Farm Trials and Farm Surveys. Collaborators - Purdue University and the Semi-Arid Food Grain Research and Development Program in Cameroon (SAFGRAD/Cameroon).**

6. **North Benin Farm Survey. Collaborators - Purdue University and the Semi-arid Food Grain Research and Development Program in Benin (SAFGRAD/BENIN).**

7. **Burkina Faso Farming Systems Data Base. Source Institutions - ICRISAT, IITA, The World Bank, Purdue University, USDA, University of Hawaii (IBSNAT), and Washington State University.**

8. **The Niger Phosphate Trials Data Base. Collaborators - International Fertilizer Center (IFDC) and ICRISAT Sahelian Center, Niamey.**

9. **West Africa Literature Data Base. Purdue University.**

**Niger Experimental and Farm Trials.** This data base consists of Farming Systems survey data (plot characteristics, family labor times, non-family labor times, consumption of materials, use of animal traction, and harvest results), river area supplementary data (ethnic group membership, household demographics, livestock inventory, and tools inventory), and on-farm trial data (yields and labor times, 1984-88). The data base is in compressed format (using PKWARE software) and in dBase syntax. The documentation covers installation, a list of variable definitions, a case count breakdown and dBase III+ usage notes.

**The North Jordan Farm Survey Data.** This data base includes two separate random samples of 60 different farming operations in the Mafraq region of Jordan for the 1987-88 and 1988-89 cropping seasons. These surveys cover most aspects of the farmer's operations, including information about the history and present nature of land holdings (eg., is land rented, owned or sharecropped), and the reason why farmers are not adopting productivity enhancing technologies such as fertilizer.

Data generated in the survey includes information about the costs and returns from crop and olive production, ie., costs of seed, labor, tillage, harvesting, total grain, straw and olives harvested, production sold or fed to animals, returns from grazing animals. Livestock holdings, grazing patterns, marketing practices and the costs and returns to animal production is included. Information about the composition of the farm family, off-farm sources of income, family spending habits and future farm planning strategies is also part of this data base.

The preparation of crop enterprise budgets based on these survey data is underway. When completed these budgets will be part of our Jordan data base. Budgets have been developed for both barley and wheat for four different categories of farms: crop only farmers; crop and livestock farmers; crop, livestock and olive farmers; and, crop and olive farmers. Budgets are now being put together for livestock and olive activities for each farm category.

The farm survey data for both cropping seasons has been compiled on 31 separate personal computer files in SYSTAT (The System for Statistics). SYSTAT combines the features of a database program such as DBASE and a statistical analysis package. The SYSTAT program, therefore, provides for ready statistical analysis of survey data in a PC environment. The primary investigator responsible for this Survey was Mr. Mahoud Oglah of the Farm Resource Management Program, International Center for Agricultural Research in the Dry Areas (ICARDA/FRMP). Co-investigators were Dr. Abdullah Jaradat of the Jordan University of Science and Technology, Irbid (JUST) and Dr. Richard Tutwiler (ICARDA/FRMP).

**The North Jordan Field Trial Data.** This data base is comprised of information derived from five experimental trials carried out in the wheat and barley areas of Northern Jordan under the direction of Dr. Abdullah Jaradat. Two sets of experiments were done at the Ministry of Agriculture's Ramtha Experimental Farm near Irbid. Three others were performed on the Jordan University of Science and Technology (JUST) experimental farms in Ramtha, Rihab (25 km south-east of Ramtha), and Bel'ama (40 km south-east of Ramtha.

The Ministry of Agriculture Ramtha data base is drawn from two separate factorial experiments each measuring barley grain and straw yield associated with: four crop rotations, viz., barley-lentils, barley-medic, barley-vetch, and barley- fallow; crop-years 1986-87, 1987-88, and 1988-89; total annual rainfall of 297mm, 300mm and 148mm; and, in one case, three levels of nitrogen fertilizer ( 0, 30, and 60 kg/ha) and four levels of phosphorus fertilizer (0, 40, 80, 120 kg/ha). In the second study, the fertilizer applications were replaced with tillage and herbicide practices, ie., three levels of tillage (no-till, 8-10 cm, and 20cm), two levels of herbicide application (0 and 2-4-D). This data has been compiled as SYSTAT data files for PC access.

The data base coming from the JUST stations includes the results of two experimental trials. The first was a factorial experiment measuring grain and straw yield during the 1988-89 crop-season for two varieties of barley (local/traditional vs improved)

in association with: two fertilizer treatments (0 and recommended N and P); two methods of sowing (hand-broadcast vs drill); and, two harvest methods (hand vs power combine). The second, for the same crop-year, was a complete block designed experiment to determine the fodder yield of 8 varieties of fodder legumes with management held constant.

This data has also been compiled as a SYSTAT system.

**The Niger Dryland - Irrigated Farms Data Base.** This data was collected by Eric Bomans in 1984-86 while he was working for the European Fund for Development (FED in French) in collaboration with the National Office of Irrigated Perimeters (ONAHA in French). The data is organized in a SAS (Statistical Analysis Software) data base. It covers information at the village, farm, field, and crop levels. Both physical and economic variables are included. The data is also available in ASCII format and can be readily read using software other than SAS. A full documentation is presently being developed, including a full description of the variable fields, SAS usage notes, and direction for implementation using PKWARE ZIP and UNZIP statements (to save place, the data is archived in compressed format.) It is expected to be ready by January 31, 1990.

**The North Cameroon Farm Trials and Farm Surveys Data.** There are four components to this data base, viz., baseline information, production information, results of agronomic experiments, and soils and weather data.

The baseline data covers family characteristics, off-farm employment and income, and related information for a sample of 220 farms in the Northeast Benoue region of North Cameroon (Sudan-Savanna) taken during 1986, 1987, and 1988. Production data includes information drawn from interviews with 130 of the baseline farmers covering: the complete calendars of operation; labor requirements (by age and sex, family vs hire); equipment and animals utilized; area planted; quantity harvested and stored (by type of storage facility and length of time); sales; consumption; and prices paid and received for 10 crops over two years (1988 and 1989). A subset of the production data for 42 farms provides detailed information on the care and upkeep of farm draught animals. Agronomic data is based on the results of three years on-farm trials conducted during 1986, 1987 and 1988 in the same region. Trial data includes: varietal tests for maize, sorghum, groundnuts, and cowpeas; soil-water conservation techniques (tied-ridges and simple ridges); and organic (manure) fertilization. Last, this data base includes soils analyses for the agronomic trial sites, and rainfall data, viz., long-term (1948-1988) for the region plus rainfall and temperature at the trial sites for each year of that experiment.

Full documentation of this data base has been completed. It includes implementation (using PKWARE archiving software), variable field description, and SAS usage notes. There is a hard copy user guide and three PC diskettes.

**The North Benin Farm Survey Data.** This data has not yet been entered into the

TSMM/EC data base. Ms. Manahil Elkhidir, a Purdue M.S. student has recently completed an analysis using these data which were provided to her by TSMM visiting scientist Dr. Dezi Ngambeki just prior to his departure from Purdue in June, 1990. At this point in time we are waiting for Ms. Elkhidir to provide us the data and necessary documentation.

**Burkina Faso Farming Systems Data Base.** This data base brings together the information related to a typical farm situation in the northern Guinean/southern Sudanic agroclimatic zone of West Africa. This database is utilized in SECURE to evaluate the attractiveness of farm practices which reduce soil erosion and enhance moisture holding capacity under uncertainty. The information in this database can be divided into following five categories: A) Typical Farm Setup, B) Crop Production, C) Enterprize Economics, D) Soil and Weather, and E) Findings of Experimental Trials. Various components of these categories and their sources are summarized below:

a) **Typical Farm Setup Data:** covers farm family characteristics such as age, size, consumption needs,off-farm income, farm workers/labor hours available for farming, etc. Source: Aillery and Day (USDA); Krause (MSU).

b) **Crop Production Data:** consists of information on crops, planting schedules, crop operations, tillage/planting methods, crop residues, crop rotations, etc. Source: Aillery and Day (USDA); Lal (IITA), Matlon and Fafchamps (ICRISAT); Nicou and Charreau (ICRISAT); Ohm, et al. (Purdue University), Reij, et al. (The World Bank); Roose (SCSA), and TRA (France).

c) **Enterprize Economics Data:** includes crop enterprize budgets estimated using information related to input and output prices, inputs applied (e.g. seed), animal traction costs, etc. Source: Aillery and Day (USDA); Bishop (The World Bank); Matlon and Fafchamps (ICRISAT); Roth, et al. (Purdue University).

d) **Soil and Weather Data:** is composed of information on soil types, slope (length and degree), bulk density, soil erodibility, rainfall, soil depth, soil cover, soil management, etc. Source: Hughes (WSU); Lal (IITA), Manrique (University of Hawaii/IBSNAT); Stoop (Fields Crops Research); Tippetts, et al. (TAMS); Wischmeier and Smith (USDA).

e) **Findings of Experimental Trials:** covers crop yields, erosion-productivity effects, tillage yield adjustments, rotation effects. Source: Lal (IITA), Nicou and Charreau (Purdue University); Rodriguez (OAU/SAFGRAD); Stoop and Van Staveren and Stoop (Field Crops Research).

**The Niger Phosphate Trials Data Base.** This data is basically response data collected by Dr. André Bationo of IFDC during 1982-1986 at the ICRISAT Sahelian Center located in Sadoré, 40 km southwest of Niamey, Niger. The variables in these data include millet yield, cowpea yield (1983 only), initial soil phosphorus content, and application level

of nitrogen fertilizers and various phosphorus fertilizers. Urea was used for N fertilization, while the fertilizers used to increase soil P were Simple superphosphate, crushed phosphate rock from Tahoua (Central Niger), and partially acidulated phosphate rock from the Park-W region (Southern Niger). Fertilizer application levels included nineteen different combinations of N and P in the ranges 0-45 kg $P_2O_5$ $ha^{-1}$ and 0-120 kg N $ha^{-1}$ in the form of urea. A detailed presentation of the data is found in Jomini (Feb 1990-forthcoming). A total of 760 observations are available. There are two PC diskettes loaded with this data

**The West Africa Literature Data Base (The Niger Bookshelf).** In support of the above data base efforts, two other activities need to be mentioned here: (1) the creation, documentation and dissemination among TSMM researchers of a Niger data base and (2) assembly, cataloguing, and computerization (using an automated search feature) of about 360 titles related to the WASAT countries. This collection is called **The Niger Bookshelf** and is available to all researchers.

### E. Expert Systems

An important activity carried out in support of TSMM modeling efforts has been an examination of expert systems to facilitate the general application of analytical tools and data employed in our own studies of particular situations. Work in expert system falls within a branch of the field of study known as artificial intelligence. In these systems unstructured knowledge gleaned from an expert is encoded into a computer program knowledge base. This knowledge base can then be tapped by others for their own use even though they may not be not familiar with the technical methods underlying the relationships embodied therein. Such systems extend information and analytical power to nonspecialists. TSMM/EC collaborators at Purdue University (Department of Agricultural Economics) worked with staff of the Department of Agricultural Engineering to put together an expert system supporting one of our Niger analyses. The system is described in the following material.

**The Niger Expert System for a Feasibility Analysis of Hybrid Seed Development and Farmer Adoption.** The first expert system developed in TSMM/EC relates to the problem of creating new hybrid seed varieties and the risk associated with farmer adoption that commercial seed companies face in developing countries. This expert system is based on the Peter Ensink's Target MOTAD model and analysis described above (see Activity b-3). While Ensink's model provides very accurate information, the data required for input and the output provided is very complicated; hence, general applications to other situations require specialized expertise.

During the summer of 1989, Roxanne Dubose, a High School apprentice from the Chicago High School for Agricultural Sciences, worked in the Purdue Agricultural Engineering Department to develop an expert system computer program which will enable non-specialists in programming and operation of computer based systems analysis to carry out similar studies successfully. In effect, the expert system developed by Roxanne will serve as the on-site expert interviewing local officials and farmers in a

natural language-like interface, preparing the data obtained from the interview into the format required, running the analytical model, interpreting the tabular output and making final recommendations in English or French, depending on the language of the area.

The Dubose expert system is still in an experimental format. Through collaboration with the Purdue Agricultural Engineering Department, it was developed at no cost to the TSMM Project. It needs to be improved and tested in the field. Expert system building has significance for the TSMM project if the training objective of the project is to be fulfilled as well as the objective of serving directly the USAID missions overseas and the cooperating national agricultural research institutions. If only TSMM researchers will use the existing models, expert systems may not be needed.

### F. Case Studies

The analytical methodologies, data and computer systems described thus far were put together expressly for the purpose of analyzing important agricultural issues in locations with significant food, income and resource management problems. Using these techniques and information systems a number of studies have either been completed or are currently underway. These analyses have taken the form of case studies of typical problem situations found in the rainfed farming regions of West Africa, North Africa and the Eastern Mediterranean. More specifically these case studies are:

#### 1. Mali Case Studies

Project staff located within the Economic Research Service, USDA, took, the lead in research and analysis focussing on Mali. With assistance and input from project staff at Washington State University, a number of case studies have been completed.

a) Soil and Moisture Management in Mali: A Case Study Analysis for West Africa. John C. Day and Marcel P. Aillery.

The purpose of this case study was to determine potential economic benefits of soil water conservation in the Sahel. A typical rainfed farming system in the Kita region of western Mali was the unit of analysis. Analytical methodologies used were the Soil Water Balance/Crop Response Model (Section III., Part A., page 7) and the Mali Whole-Farm Linear Programming Model (Section III., Part B., page 10).

The typical Kita farm is located in the Sudano-Guinean agroclimatic zone where mean annual rainfall is about 1075 mm with standard deviation slightly above 200 mm. Soils are poor (predominantly Alfisols), farm size is relatively small (8 hectares), and family size large (12 members but only 5 FTE workers). Production follows traditional practices with no modern inputs used except for small amounts of NPK fertilizer (24, 8 and 32 kg/ha respectively). Crops grown are traditional long-season varieties (LSVs) of Sorghum, Millet, Maize, Rice, Groundnuts and vegetables. Little marketable surplus exists except during good years. High evaporation and runoff and low soil water holding capacity

leads to moisture stress and reduced crop yield.

The analysis produced estimates of the increased farm income and production benefits stemming from on-farm water conservation. Specific water conserving technologies were not examined because of data limitations at the time. Economic benefits, therefore, are the gross returns to having more water available for plant uptake in the soil profile . These income gains provide an indication of farmer's ability to pay for water conserving technologies.

By improving rainfall infiltration from typically low rates of 40 percent up to 60 percent, and using the usual small amount of fertilizer, farmers could double income in poor rainfall years and quadruple it in average years. If infiltration rates were increased to 80 percent income with both rainfall scenarios could be raised another 50 percent. Food grain production could increase 60 to 80 percent with water conservation.

Principal conclusions from this initial TSMM/EC case study are that water conservation benefits are very large and potentially profitable in traditional farming systems of the Sahel, and that the integrated Soil Water Balance/Crop Response Model and the Whole-Farm Modeling methodology developed and applied here are very useful effective analytical tools for evaluating soil, water, and related farm management technologies.

b) Water Conservation in Arid and Semi-arid Agriculture: An Economic Analysis. John C. Day.

In the study just described (above) specific technologies or farm management practices for soil moisture conservation were not evaluated because of data limitations. Hence, a notable feature missing was the cost associated with water conservation. This particular study, therefore, represents a significant improvement in that an on-farm water conservation technology is now included as an alternative production practice. The technology is that of manually constructed tied-ridges, and the focus is on the economic and production benefits in the context of a typical rainfed farm in West Africa.

The Kita representative farm is again the unit of analysis, and as before the Mali Whole-Farm Model and the Soil Water Balance/Crop Response Model are the primary tools of analysis. Labor time and cost required for construction of the tied-ridges, the increase in soil moisture, and the resulting crop yields are estimated and explicitly taken into account.

The analysis shows that water conservation through tied-ridges can result in significant increases in crop output and substantial economic benefits to farmers. The gains, however, are sensitive to the labor cost of the ridging, seasonal rainfall, and the infiltration efficiency achieved. If the ridging is done during peak labor demand periods when wage rates are high, and if the resulting infiltration rate is no more than 60 percent (even with fairly good rains) net farm income gains would be no higher than 6 percent and possibly even negative. On the other hand, if infiltration was improved to about 80

percent of rainfall increases in net farm income could range from 120 percent with poor rains and peak labor demand to 375 percent with average rains and slack demand.

During low rainfall years farmers could economically increase production of grains (sorghum, millet, rice, and maize) from 41 percent to 57 percent if they could only do a better job of capturing more rainfall in the soil. Under rainfall conditions that might be expected half of the time production of these crops could increase 88 percent with additional water conservation efforts. Because fertilizer levels were held to very low levels in both the base scenario as well as the tied-ridge scenario, the production and economic gains are due to water conservation.

c) Crop Variety Selection in Response to Rainfall Variability in Dryland Agriculture: A West African Case Study. John C. Day and Walter R. Butcher.

The case studies described so far have looked at the most serious problem in the Sahel--rainfall and soil moisture limitations. The specific technology examined thus far has been tied-ridges. Tied-ridges can increase the supply of moisture available to plants by increasing rainfall infiltration. The previous study showed that this approach can be economically profitable and output increasing compared to the traditional situation.

Another approach to dealing with Sahelian weather is the use of quicker maturing crop cultivars. Short-season varieties (SSVs) have an impact on the demand side of the water balance equation. Together with flexible planting dates, these varieties can bring plant water demand into line with available soil moisture. For example, in the event of late-onset of the rainy season SSVs can be planted later and still reach maturity. In order to analyze this option, a case study involving 90 day cultivars of cereals and groundnuts in addition to the traditional 130 day varieties was carried out. Also included, was the use of animal power for plowing and ridge construction as a general improvement over manual tillage. Animal traction is primarily labor saving, but can also improve infiltration from early season rains during and following land preparation.

In our family of case studies, crop cultivar selection now becomes an additional response the farmer may make to the often low and always uncertain rainfall, and animal power is an alternative to manual tillage.

The basic methodology followed in this study is the same as before. Input/output coefficients have been added to the models to reflect the short-season crop options and the fact that farm resources include an oxen team. Crop yields due to more timely plowing, ridging and tieing, and infiltration enhancement have been adjusted. Production must now satisfy animal feed requirements as well as farm family food needs.

The optimal farm plan is to perform all tillage operations with animal traction, apply tied-ridges to all cereal crops, and sow SSVs with late planting on about 40 percent of the farm land with the balance in early planted LSVs. The optimal mix of measures results in saleable surplus of grain large enough to result in a 10 fold increase in income compared to the situation where the only improvement is a small amount of fertilizer. Total grain production increases by about 20 percent. However, income gains associated

with the short-season varieties are about 6 percent, and the change in food output is negligible.

The most important conclusion from this particular study is that animal traction in combination with tied-ridges is highly profitable compared to a base case where these options are not employed. Animal traction seems to improve the potential of traditional long-season varieties even with poor rains. On the other hand, the contribution of short-season varieties is largely in helping to meet minimum family foods need in the event of poor rains.

d) Data Base Integration for Agroclimatic Analysis and Planning.
E.T. Kanamasu, J.C. Day and J.P. Milford.

This study is an interdisciplinary examination of basic data useful for agricultural development and planning. There are three main parts to the study. The first part deals with agroclimatic data, ie., it describes types of data most useful and data sources. The second part illustrates the use of agronomic and agroclimatic data to produce useful information for farm planning. The last part is an economic case study illustrating the integration of agronomic, agroclimatic, and economic data in a whole-farm analysis of farm planning options.

The economic study is an extension of previous case studies based on the Kita representative farm of Mali, the Mali Whole-Farm Model, and the Soil Water Balance/Crop Response Model. As in the preceding study, the technologies examined are small amounts of NPK fertilizer, long- and short-season cultivars, tied-ridges, and animal traction. As before, the objective is to identify the economically optimal combination of these measures given that either rainfall capable of producing long-term average yields, or very poor rains occur.

The format of this analysis is a comparison between three different situations, ie., a base case where light fertilizer and animal traction is possible, a case where only short-season varieties are added, and a third case where both short-season varieties and tied-ridges are added to the basic set of choices. Production sufficient to satisfy family food needs even in the event of very poor rains is a necessary condition in all three situations. Feed production may or may not happen, hence animal traction may not always be a viable option.

Compared to the situation where only traditional long-season cultivars are planted and water conservation is minimal, the inclusion of short-season varieties in the list of management options affects both planting date and the choice of cultivar. With this option the optimal planning strategy calls for 40 percent of the grain crop to be made up of short-season varieties and a shift from early season planting (late May) to later planting (end of June). Farm income and grain production, however, do not change very much.

In contrast, if soil moisture levels are improved through tied-ridges, late planting of short-season crops gives way to early planting of the longer-season varieties, and

farm income and grain production both increase by about 20 percent over the base. Clearly, potential productivity increases are greater with water conservation measures than with short-season variety selection.

These results demonstrate, once again, that even with animal traction if adequate measures to protect water supplies are not carried out basic family food needs are best met through a combination of improved short-season cultivars and the traditional longer-season varieties. The quicker maturing types provide a higher degree of harvest certainty in the event of poor rains than do the longer season crops. However, with tied-ridges in the farming system, early season precipitation even though limited can be captured, thus making long maturing crops both a secure and more profitable choice.

e) Economic Analysis of Soil and Moisture Management on Marginal Croplands.
Walter R. Butcher and John C. Day.

The previous case studies have all focussed on various aspects of soil moisture and soil fertility problems in the Sahel. The techniques examined have been production practices (animal traction and tied-ridges) and farm management decisions (the choice of long-season and/or short-season cultivars, and planting date). Production, income, and resource use changes that might be expected with adoption of these measures were estimated. However, a very important factor not taken into account in any of these studies is soil erosion.

Due to the particular characteristics of soils, weather, and farming practices carried out in the Sahel, soil erosion is high. If long-run sustainability of agriculture in this environment is to be achieved this must be brought under control. The Case Study summarized here has a broader perspective than the others in that soil erosion associated with the technological packages under study is estimated and given an economic value. Soil erosion damages now becomes a part of the evaluation process and a critical decision variable in choosing technology and management options.

The Study actually has two main objectives: (1) to estimate the effect of soil erosion on the optimal farm plan, and (2) to estimate the effect of different minimum family food subsistence levels on the plan.

The erosion component involves a comparative analysis for a case where soil erosion damage is not prevented, and a case where erosion is reduced through the introduction of tied-ridges. (Tied-ridges generate soil conservation benefits as well as water conservation benefits.) The analysis is a "with/without" tied-ridges evaluation with the focus only on the erosion impacts of T-R. The basic technology packages examined are: long-season crops, small amounts of NPK, animal traction, and four plant date alternatives, and all either with or without the tied-ridges. Short-season varieties were not part of either package.

Soil erosion is estimated using Universal Soil Loss Equation (USLE) parameters. Erosion damage is based on the value of output foregone because of lost productivity.

This current-year damage is then projected for 5 and 20 year time horizons and discounted at 9 percent. The present value of damage then represents the cost of current-year erosion, plus the discounted value of that loss for each year in the future.

Results of the erosion analysis are that in an optimal farm plan with a 5-year time horizon tied-ridges can (1) reduce erosion by 77 percent (from 36 tons per hectare to 9 tons) and, correspondingly, damage PV from 378,000 Malian Francs to 84,000, (2) increase food grain output by 21 percent, and (3) raise net farm income by over nine times. With a 20-year time horizon these positive benefits are only slightly lower, because while there is an additional 15 years of erosion damage the discounting process tends to dampen the significance in present value terms.

The general conclusion to be drawn is that soil erosion control can make a major difference in the economics of farming in the Sahel and help increase food output. Obviously, it also helps to maintain the long-run sustainability of the farming system. More specifically the Case Study shows that tied-ridges are economically feasible strictly as an erosion control device and that the magnitude of the benefits are very large. This is true no matter what time horizon one adopts. If moisture conservation benefits are added to the erosion control benefits (as we do in the next Case Study) tied-ridges become an even more attractive technology for the Sahel.

The principal effects of relaxing the family food requirement constraint is an inter-related change in the optimal cropping mix and an increase in net farm income. If sorghum/millet food requirements are lowered by just 10 to 20 percent, that permits a shift from Sorghum to Maize. The increased Maize output is then marketed, thereby, increasing sales and raising income by 50 to 77 percent. The conclusion to be drawn from this is that if farmers exercise flexibility as they plan for food needs they can be better off, providing marketing possibilities exist. In addition our Study shows how sensitive farm model results are to a constraint that may be very arbitrary in terms of its specificity. As we have seen, modeler specified minimum levels of production for individual crops on the grounds of perceived need for "variety" in the diet can have profound effect on model solutions and the recommendations therefrom.

f) An Economic Analysis of Farm Management Practices and Improved Technologies in the Sahel. John C. Day, Walter R. Butcher and David W. Hughes.

Having raised the issue of soil erosion and investigated the erosion control benefits of tied-ridges in the previous Case Study, there remains the question of how these considerations affect decisions in the context of the full set of management options, including the minimal input situation. This last Mali Case Study sheds light on that issue.

The previous case studies have all looked at various combinations of basic production practices judged to be feasible adaptations to the traditional calendar of operations. The use of short-season improved cereal varieties requires very little

adjustment to the usual farm plan. Tied-ridges call for some changes and place extra demand on labor, but are not overly disruptive in that ridging is already a common practice. Adding the "ties" becomes a marginal adjustment. A technological advance of some complexity, however, is the use of animal power. This option is now added to our analysis. (The literature on appropriate technology covers the issues pertaining to adoption of animal traction in considerable detail and our case study does not attempt to elaborate on that discussion. Rather, we focus on the likely impacts were adoption to occur.)

The analysis follows the same framework already established, ie., a comparative evaluation of different technologies in the context of the typical Malian farm. Five different levels of technicity are examined using the Mali Whole-Farm Economic Model and the Soil-Water Balance/Crop Response Model. Technology levels progress from the very simple, fully traditional situation to more complex combinations of production practices and management options. A sixth case "looks" at the problem as if the farmer was not aware of, or chose to ignore, soil erosion and its effect on productivity. Technical levels are as follows:

Soil, Water and Crop Management Strategies for Case Study

| Strategy | Traditional Case | Case I | Case II | Case III | Case IV | Case V |
|---|---|---|---|---|---|---|
| Fertilizer | - | X | X | X | X | X |
| Tied-ridges | - | - | X | - | X | X |
| L-S Cultivars | X | X | X | X | X | X |
| S-S Cultivars | - | - | - | X | X | X |
| Four Plant Dates | X | X | X | X | X | X |
| Animal Traction | - | X | X | X | X | X |
| (Long-term Erosion Accounted For) | X | X | X | X | X | - |

In the Traditional Case, even with optimal planning against average and poor rains, net farm income will not be very high. First of all, there is little saleable surplus beyond basic family food needs. Secondly, real farm income is depressed by the present value of future productivity lost by erosion during production of the current crop. Erosion is high -- 32 tons per hectare. The present value of the damage stream for 10 years at a 9 percent discount rate is 343,000 MF. Planting takes place in only two periods. Seventy percent of the land is early-planted (May 15-June 1) and the balance in period 3 (June 15-June 30). This is a realistic picture of what is actually happening in the subsistence sector. However, as additional technical options become possible the situation changes.

Fertilizer (even in small amounts) plus animal traction (Case I) could increase net farm income by more than 300 percent and food production by 12 percent, but soil erosion would also increase slightly to 33 tons. Planting is now spread out over the first

three periods -- 47 percent in period 1, 39 percent in period 2, and 14 percent in period 3. This represents a slight shift toward earlier planting made possible by a little animal traction. Only 38 hours of rented ox team is utilized. Plowing accounts for the increase in erosion.

Introducing tied-ridges (Case II) increases net farm income by a factor of 43 and production by 35 percent. At the same time soil erosion is decreased by 72 percent to 9 tons per hectare. In this Case the large increase in income arises from additional current-year food production (due to higher yields) which in turn permit a large increase in saleable surplus, plus increased present value of future productivity due to less erosion with the current crop. The soil and water conservation benefits of tied-ridges alone in this comparison amount to 249,000 MF in present value terms for a benefit-cost ratio of 2.7. By increasing yields, the tied-ridge strategy supports the purchase of an oxen team, makes greater use of early-season rains through earlier planting (92 percent in periods 1 and 2) and permits the hiring of additional labor.

Short-season cultivars (Case III) make no contribution. Short-season crops have a yield advantage over long-season varieties when late onset or early cessation of rains result in a short growing season. The potential advantage of the short-season varieties did not come into play because onset under both scenarios was sufficient for early planting. It is likely, however, that in a year with late onset the short-season crops would be a better choice. For the same reason the new combination of short-season varieties and tied-ridges (Case IV) makes no significant difference compared to tied-ridges alone (Case II).

The production plan of Case V represents a situation in which the farmer gives no weight to the long-term benefits of soil conservation. The first year gain in productivity due to soil moisture conservation with tied-ridges is accounted for, but the long-term loss in future soil productivity because of erosion caused by current farming practices is not. In Case IV, on the other hand, the long-term soil-conserving benefit of tied-ridges is recognized as are the immediate moisture retaining advantages. Accordingly, there is a reduced use of tied-ridges in Case V compared to Case IV resulting in somewhat lower profits and increased erosion rates of 4 tons per hectare. Case V represents a situation of misperception by the farmer who ignores erosion costs. In both Case IV and Case V, however, the adoption of yield boosting technologies results in higher profits and improved treatment of the soil resource base as compared to the Traditional Case

### g) General Conclusions from the Mali Case Studies

NOT COMPLETE! STILL NEED TO WORK IN IDEA THAT SAHEL SITUATION IS SERIOUS BUT NOT HOPELESS, COMPLEX BUT NOT IMPOSSIBLE, REQUIRES MULTIPLE APPROACHES (NOT PACKAGES), NOT SINGLE SOLUTIONS, IS DOABLE.

These analyses indicate that even in the relatively humid Sudano-Guinean zone of the Sahel where the Kita representative farm is located improved soil, water and crop management technologies are cost-effective and yield high benefits in the form of

increased income, production and erosion control. Even with traditional cultivars the combination of chemical fertilizer and tied-ridges proved effective. Of major significance in these results is the increased stability in year to year output made possible by the water conserving tied-ridge technology. Similarly, the erosion control benefits of the practice further enhances the long-run sustainability of farming in the Sahelian environment.

On the other hand, short-season (90 day) cultivars made no significant difference in farm output or income. However, in situations where seasonal distribution of rainfall is less favorable than the scenario examined here, such as later onset/earlier cessation, short-season cultivars would very likely be a better choice, ceteris paribus, than traditional varieties. This would be particularly true in the drier northern regions of the Sahel where growing season length is normally shorter. Also, in the drier regions where water is even more scarce the economic returns to water conservation may be larger than estimated here.

Farms and farmers in other locations with characteristics similar to those of our representative Malian farm could experience similar gains, certainly in the short run. Clearly, there is a latent economic incentive for adoption of new practices. For that reason public policies and programs should be much more natural resource oriented than they have been to date. Vigorous action to remove impediments to diffusion of better resource management at the farm level is needed. This, after all, is where most soil and water resource use decisions are made. And, it is here where most improvements must take place.

In the long run, the farm level benefits of technological change depend on the extent to which the collective actions of many individual adopters affect the total demand for inputs, commodity supplies and related input/output price ratios. If a large number of farmers were to adopt technologies that significantly increase output, farm gate prices could be depressed and the incentive lost. Similarly, a large shift in demand for production inputs might raise costs. Thus, the aggregate effects of technology adoption should be examined and policies put in place to create an economic environment wherein technology adoption remains a profitable choice for the dryland farmer. In the long run, Sahelian society-at-large stands to benefit from this support.

**2. Niger Case Studies**

A number of case studies have been developed by TSMM/Economics-PURDUE. These are:

a) Stochastic Linear Response and Plateau Functions in Modeling Crop Response to Fertilizer in Niger, West Africa. Patrick Jomini, Robert R. Deuson, Jess Lowenberg-DeBoer and Andre Bationo.

Soil fertility is believed to be a major constraint to food production in many regions of the West African Semi-Arid Tropics (WASAT). Low-level chemical fertilization is believed

to be an economically viable strategy to increase and stabilize food production in the area. Since 1982, the International Fertilizer Development Center (IFDC) has collaborated with the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) on an extensive fertilizer research program. This includes research on the appropriate amount of nutrients to apply as well as the appropriate source to be used.

Two alternative sources of phosphorus (P) have been identified in experiment station trials. They are: 1) crushed phosphate rock from Tahoua (Central Niger), and 2) partially acidulated phosphate rock from the Park W region (Southern Niger). These alternative sources are compared with commercially available simple superphosphate.

The main objective of this research is to determine economically viable means by which to manage soil fertility in the dryland, millet-producing area of Niger. The specific objectives of this study include: 1) to identify economically viable levels of soil fertility maintenance; 2) to identify the most appropriate source of P in light of the constraints facing farmers; and, 3) to identify key factors likely to affect farmers' decisions to use fertilizer-based technologies. These factors include: a) the carryover effects of nutrients from one cropping period to the next; b) the effect of weather-related risk on farmers' decisions to use fertilizer technology; c) the role of financial resource constraints in adopting fertilizer based technology; and d) the effect of both input and output prices on farm income and the use of fertilizer-based technologies.

The methodology followed consists of first estimating fertilizer response functions for millet that depend on environmental (soil and moisture) conditions. These response functions are developed using the Linear Response and PLateau framework (see Section III., Part B., page 12, and the Niger Phosphate Trials Data Base, Section III., Part D., page 23 above) which is based on the premise that plant growth is governed by the "law of the minimum", a concept that is appealing to agronomists. Next, nutrient carryover functions are estimated based on the concept of nutrient balance, and accounting for all additions and subtractions of nutrients to the and from the soil nutrient stock. Then, these relations are incorporated into a static decision-making framework assuming risk-neutrality (profit maximization); this simple model is used to provide adequate understanding of the way in which biological relations and economic variables relate to each other. This leads to better understanding of a dynamic decision-making framework wherein farmers are assumed to be averse to risk (expected utility maximizers). Last, estimated fertilizer response surfaces are brought into a multi-year economic decision framework. This framework is of the discrete sequential stochastic program (DSSP) class in order to account for the potential effects of carryover nutrients in the decision to fertilize. The DSSP model reflects the choices available to farmers in Western Niger and incorporates the possibility of using the alternative sources of P mentioned above at different prices. The financial and risk-bearing characteristics of farmers are modeled in order to address the issues constraining farmers from adopting fertilizer-based technologies.

Preliminary results indicate that moderate levels of P can profitably be applied by farmers who operate on sandy, P-starved soils commonly encountered in Niger. This result holds when farmers are assumed to be risk averse and for a wide range of relative input/output prices. In addition, Simple Superphosphate is superior to the native

phosphate sources due to its high solubility (which results in high immediate benefits) and the current price structure which does not reflect the relative degree of solubility of the three products tested. Finally, given the current slump in good rainfall years and the variability observed in the response to N, application of this nutrient at current price levels would not be profitable or desirable in most years.

b) Risk Sharing Systems for International Development: The Nigerian Case. M. A. Krause, R. R. Deuson, T. Baker, P.Preckel, J. Lowenberg-DeBoer, C.K. Reddy and M. Kadi.

The problem analyzed here is that of providing low cost credit to Nigerien farmers in the face of mounting production and price risks. The purpose of the research is to determine the effects of several factors on the adoption of technologies recently developed by the National Agronomic Research Institute of Niger (INRAN). The factors studied are: the rate of interest on credit, the amount of farmer equity, credit repayment insurance based on weather, and risk sharing by suppliers of labor and fertilizer.

Discrete Sequential Stochastic Programming or DSSP was the analytical methodology used to obtain a simultaneous focus on technology adoption and credit (see Section III., Part B., page 11). In addition, a biological simulation model of intercropped millet and cowpea production is used to estimate the yields for the 21 years representing different state of nature in the DSP model drawing upon Niger Experimental and Farm Trial Data Base (Section III., Part D., page 20).

The analysis indicates that offering low interest credit is a relatively ineffective way to encourage the adoption of agricultural technologies in Niger. A risk bearing credit program in which the level of debt repayment was dependent upon weather was found to increase technology adoption.

c) A Simulation Model of Millet and Cowpea Intercrop (Case Study Analysis). J. Lowenberg-DeBoer, M. Krause, R. Deuson and K. Reddy.

This case study involved a comparative analysis of four technologies for producing millet and cowpea in low rainfall regimes in Niger. The Millet-Cowpea Intercrop Model described above (Section III., Part A., p. 8) was used to estimate crop yields with simulated weather conditions based on 17 years of weather data and the Niger Data Base (page 20). The technologies examined were: T1, the farmer's traditional crop varieties and methods; T2, improved crop varieties with traditional agronomic practices; T3, improved crop varieties with increased planting density; and T4, improved crop varieties, with increased planting density and nitrogen and phosphate fertilization. First, yield distributions for both crops with these technologies were ranked and compared. Next, using stochastic dominance techniques, the technologies were ranked on the basis of millet yields as well as net cash income per hectare to intercropped millet and cowpea. These stochastic dominance rankings provides an assessment of the yield- profitability-

risk characteristics of each technology package in the on-farm trial data relative to the other packages.

The simulated yield distributions for millet indicate that treatment T2 may increase millet yields with only a small increase in variability, but that treatment T3 may sacrifice millet yield for improved cowpea production. The fertilizer in treatment T4 more than doubles average yields and almost triples the standard deviation of yields. These simulations indicate that the variability of yields under treatment T4 increases largely because of increased yields in the years of high rainfall. T4 yields are never below the yields in the other treatments. It should be noted that this is consistent with the observed and simulated millet yields, ie., T4 is always superior to all other treatments, and T2 is always superior to treatments T1 and T3. The rank of treatments T1 and T3 depends on the year; sometimes treatment T1 has the higher millet yield, and at other times treatment T3 has the higher millet yield.

The simulated yield distributions for cowpea indicate a substantial increase in yield and variability with the increased density in treatment T3. As in the millet distributions, the fertilizer in treatment T4 generates a higher mean yield and greater standard deviation than the other treatments. In the model, the introduction of an improved millet variety at the traditional density (treatment T2) has little effect on the cowpea yield; thus, cowpea yield distribution for treatments T1 and T2 are almost identical. In each year simulated, the yield under treatment T4 is greater than the yield under treatment T3 and, in turn, the yields of both treatments T3 and T4 are greater than the yield for treatments T1 and T2. This ranking of the treatments does not always hold in the observed yields. The yields for Maiguéro in 1987 show a treatment T3 cowpea yield higher than the treatment T4 cowpea yield.

In general, both the millet and cowpea simulations show somewhat higher mean yields and wider variability than the observed yields. The higher standard deviations are to be expected because the simulations occur under a wider range of weather conditions than was experienced during 1985-1987. The higher mean yields could indicate a bias in the model, or it could be due to generally favorable weather conditions that occurred in Niger in the 1960s. Also, it should be noted that there may be some small weather difference between Maradi and Maiguéro.

The stochastic dominance test was used to compare the risk characteristics of the millet yield for each possible pair of treatment: T1 vs. T2, T1 vs. T3, T1 vs. T4, T2 vs. T3, T2 vs.T4, and T3 vs. T4. The cumulative density functions (CDFs) of each treatment were graphed, showing that T4 clearly dominates the other treatments using first degree stochastic dominance (FDSD) criteria, ie., T4 CDF is always to the right of the other CDFs. Treatment T2 dominates treatments T1 and T3 by FDSD, but is dominated by treatment T4. Treatments T1 and T3 are dominated by treatments T2 and T4, but the analysis cannot distinguish between T1 and T3. T1 cannot be dominant because it has the very lowest yield outcome, but T3 does not dominate by second degree criteria (SDSD) because it has less favorable outcomes in the upper end of the yield range. Above about 210 kg/ha, the T3 CDF is to the left of the T1 CDF. It should be noted that the formal stochastic dominance analysis confirms what was shown by a time series plot

of the simulated millet yields. The dominance of treatment T4 over the others and treatment T2 over treatments T1 and T3 was indicated by the time series plot, because treatment T4 yields are always above the other yields and treatment T2 yields are always above the treatment T1 and T3 yields. The analysis suggests that the risk characteristics of treatments T2 and T4 by themselves should not prevent adoption of these technologies, though other constraints such as lack of capital to purchase inputs or lack of access to improved seed might.

The risk characteristic of the net cash income per hectare were also compared. The potential net cash income for each year was calculated as the market value of the millet and cowpea grain minus the cost of any inputs that must be purchased. The market value was calculated at the annual average real price for the year of the simulation. This annual average price is relevant if the marketings of grain are spread evenly throughout the year. Based on the average relationship between market prices and official prices of improved seed, improved millet seed was valued at 1.33 times the market value of millet, and improved cowpea seed was valued at 1.14 times the market value of cowpeas. In the crop budgets the assumption is made that only family labor was used and that there is no cash cost for using family labor.

The analysis of the net cash income distribution indicates that treatment T4 dominates by FDSD when the target variable is income. This can be seen in a CDF graph -- treatment T4 CDF is always to the right of the others. Treatment T1 is dominated by all other treatments; its CDF is to the left of the other three. Treatments T2 and T3 cannot be distinguished, even by SDSD. Treatment T3 does, however, show up better relative to treatment T2 when good weather substantially improved cowpea production. Treatment T2 cannot dominate treatment T3 because the treatment T2 lowest value is less than the treatment T3 lowest value. The analysis of cash income suggests that treatment T4 has relatively desirable risk characteristics, and that both treatments T2 or T3 dominate treatment T1, but that the choice between T2 and T3 is not clear.

In conclusion it can be said that the improved technology package of improved varieties of millet and cowpea, increased plant density and greater fertilization is the best choice on grounds of expected yield and net income. Traditional practices in this comparison are never dominant. In terms of expected millet yield, without fertilization improved varieties at traditional densities do better than improved varieties at high density. However, in terms of net income to both millet and cowpea the choice between new varieties at low densities or at high densities is not clear because during good years the expected payoff to high density cowpea is much better than it is during low rainfall years. Thus, some technological packages are clearly dominant over all likely rainfall patterns, while the desirability of others is dependent on which weather patterns occur.

d) Analysis of the Competition for Labor by Dryland and Irrigated Crops: The Case of Rice and Millet in Niger. Ziyou Yu, Robert R. Deuson, and Jess Lowenberg-DeBoer.

The issue looked at in this Case Study is the problem of describing quantitatively the interdependency between dryland and irrigated agriculture in the Niger River Basin.

A Cobb-Douglas production function is used for this research. Considering the relatively small amount of data generated in the survey (Niger Dryland - Irrigated Farm Data Base, Section III., Part D., page 21) the statistical approach known as "efficient use of degree of freedom" is necessary. Also, the production function used in this project only includes the crop calendar as a major factor beside input factor. These two factors are imperfect substitutes. Thus, the Cobb-Douglas function is chosen. Seemingly Unrelated Regression equation estimation (SUR) is used to estimate the Cobb-Douglas function.

Results indicate that a millet-based technology should not be introduced if its application conflicts with the transplanting date for rice in the dry season. Moreover, a rice-based technology should not be introduced if its application conflicts with both planting and first weeding schedules of millet in the dry season.

e) Sorghum Technology Assessment for Southern Niger Using a Target MOTAD Approach. Peter Ensink and Robert R. Deuson.

This study addresses issues that relate to the adoption potential of improved and hybrid sorghum varieties. The specific objectives of this analysis are to: (a) estimate the cost of producing hybrid seed in Niger; (b) determine the profitability and identify the constraints to farm level adoption of the new cultivars; and, (c) determine the effect of various scenarios on the adoption of the new cultivars.

Through the use of a linear programming, Target MOTAD analysis, the profitability, yield consistency, and financial and physical resource requirements of the new cultivars were evaluated relative to those of other principal crops under various cultivation practices and risk attitudes of farmers (for model description see Section III., Part B., page 12, and for data description see Section III., D., page 20).

It was found that hybrid sorghums yield more consistently than cowpea, millet, and cotton in the rainy season, but less consistently than cotton and wheat in the dry season. Also, hybrid sorghums are more profitable than either local or improved sorghum varieties under improved cultivation practices, i.e. irrigation with fertilizer use. When the model was used to analyze the effect of setting the farm wheat price at the world wheat price and reducing input/output price variability, the new sorghum cultivars were adopted year-round by risk averse producers, and on all available land in the dry season by risk neutral farmers.

**f) General Conclusions From Niger Case Studies**

(To be completed)

## 3. Jordan Case Studies

Project staff at Washington State University took the lead in research and analysis focusing on Jordan. A number of case studies have been completed.

a) Examining the Optimal Use of Cereal Grain and Straw in the Mafraq Region of Jordan with a Mixed Integer Programming Model. David W. Hughes, Walter Penaranda, Abdullah Jaradat and Walter R. Butcher

Cereal crop straw and grain residues are an important source of livestock feed in mixed livestock-cropping systems throughout the Middle East and North Africa. Cereal straw is often gathered along with grain harvest and stored for livestock feed. Croplands are generally grazed following harvest until livestock have consumed virtually all remaining above ground biomass--spilled grain, stems and leaves, and weeds. Another common practice, especially in dry years when grain yields are low, is grazing of the standing crop--grain as well as stems and leaves--in lieu of harvesting.

Both crop and livestock production decisions obviously must take into account the substantial economic value of feed that can be obtained from grazing of cereal crops. This case study examines the graze versus harvest decision in the context of alternative seasonal feed sources and livestock management options.

The decision to graze rather than harvest a crop rests on the relative profitability of two alternatives:

1) returns to the harvested output net of harvesting costs versus;
2) returns to the crop as a grazed input to livestock.

Net returns in the harvest alternative equal returns to the harvested output minus the costs of harvesting, processing and storing crop grains and residues. Total returns to the harvested output depend on cereal grain and harvested straw yield and selling price, or, if the harvested output is fed to own-farm animals, the marginal value of the harvested grain and straw as a feed source. If crop yields tend to be low, returns to the crop as a grazed input to livestock may exceed its net value as a harvested commodity.

The harvesting or grazing decision is dependent on expectations about crop prices and the availability of alternative feed sources through the crop year. If alternative feeds are anticipated to be in relatively short supply in the fall, winter, and spring months, then the farmer is likely to value more highly his harvested crop as a hedge against short feed supplies. Likewise, if the farmer anticipates relatively high market prices for cereal grains and residues, he may choose to harvest and sell his crop. On the other hand, if alternative supplies of summer feed sources such as native pasture are in short supply and market supply of purchased feeds are expected to be relatively plentiful, the decision to graze becomes more attractive. Finally, the farmer can increase or decrease the size

of his flock in light of the availability and costs of the various feed sources and the market prices of livestock and crop products. Changes in flock size also involve long-term farmer expectations because the flock is a productive asset that will influence farm net returns in future years.

Model results showed the harvest versus graze decision to be sensitive to changes in family harvest labor supply, livestock output prices and crop productivity. Grazing a portion of barley crop is optimal in a typical dry year where crop yields were low. In a year where crop yields attain expected levels, it is optimal for the farmer to harvest all of his crop production. Decreasing available family labor supply causes even more of the barley crop to be grazed rather than harvested in the typical dry year case. Decreasing available family labor would result in a small portion of the crop being grazed rather than harvested even in a good year. A 50 percent increase in livestock prices tripled the size of the farm sheep flock and it would be optimal to feed all barley grain to the flock plus the limit allowed in purchased barley and wheat bran. It is also optimal to graze 0.9 hectare of standing barley even in a typical crop year.

Grazing a crop in lieu of harvest is an important farmer option in years when crop yields are low. The decision to graze in lieu of harvest is influenced by variables such as crop productivity, family labor supply, livestock product prices, and availability of alternative feeds. The farmer ability to minimize risk and profit loss through the graze in lieu of harvest options needs to be accounted for in examining the profitability and risk of crop livestock operations in the region.

b) Economic Evaluation of Long-term Productivity Effects of Alternative Barley Farming Systems in Northeastern Jordan. David Hughes, Walter Penaranda, Walter Butcher.

Farmers in the barley-fallow area in northeastern Jordan follow practices that tend to deplete soil resources and lead to a general downtrend in productivity. Practices that would help to conserve soil and sustain productivity (incorporating crop residues into the soil, including legumes in crop rotations, adding fertilizer, and using conservation tillage) are almost never employed by typical farmers in this area.

The EPIC computer model was used to predict future yields over a 50-year period of following various combinations of conventional and conservation practices. Under continuation of conventional barley-fallow rotation with all residues harvested and no fertilizers applied, productivity is projected to continue to decline to about one-half of current levels by the end of the 50 years. About three-fourths of the productivity decline is attributed to declining fertility of the soil with only about one-fourth due to the effects of wind erosion on productivity. Application of nitrogen and phosphorous fertilizer and incorporation of residues would lead to a predicted doubling of barley yields in all except the driest years, and the higher yields would be sustained with very little decline over the 50 years.

Net farm incomes, including returns from both crops and livestock, are predicted to be increased about 10 percent in the short run from application of fertilizer with no other changes. A farm that continues to apply fertilizer throughout the 50-year period could expect to be earning about 50 percent more than if the same rotation and practices had been followed with no fertilizer applied. Incorporation of residue without fertilization would provide only a small short run increase in grain yields and, in the long-run, would have only a modest effect on forestalling productivity depletion. Income would be considerably reduced under this practice because of loss of the residue as a livestock feed supply. Combining fertilization with residue incorporation provides the highest and most sustained yields and income would be slightly higher, even after accounting for the effect of loss in feed supply.

c) Costs and Returns of Crop Production for Dryland Farms in the Mafraq Region of Northeastern Jordan. David W. Hughes

This case study is based on barley and wheat enterprise budgets for the Mafraq dryland farming region of northeastern Jordan. Budgets provide, among other things, estimates of farm net returns and profitability under current farm practices. The budgets are primarily based on surveys of farmer conducted in the Mafraq region in the 1988 and 1989 crop years.

Initial analysis of the survey data concentrated on dividing farm operations into various groupings (farmer strategies, farm size categories and rainfall zones) to check for statistically significant differences in enterprise operations. Analysis of variance (ANOVA) and covariance analysis indicated little evidence of statistically significant differences between farm operations based on their strategy, size of operation or precipitation zone. The statistical evidence implies that barley and wheat enterprises tend to be fairly homogeneous in terms of input use, costs and productivity.

Barley production costs for a typical operation equal 5.13 JD (Jordan Dinar) per donum (a donum equals 1/10 of a hectare). Preharvest costs are responsible for 53 percent of total costs, while harvest costs and a small operating capital charge make up all remaining costs. Actual expenditures are 2.90 JD per donum with the remaining costs consisting primarily of the opportunity costs of family labor.

Total revenue and gross margin analysis indicate that net returns to land, capital and management are 1.19 JD per donum. Therefore, under assumptions of average productivity, barley operations are profitable in the short run.

Wheat production costs are slightly higher than barley costs (5.40 JD per donum). Gross margin analysis for wheat production shows higher net returns than barley of 2.10 JD per donum because of higher selling prices for wheat grain and wheat straw. However, an evaluation of crop production over a number of years with different rainfall levels and market conditions may show a different level of gross margin and different relative margins for wheat and barley. Also, differences in inherent productivity in wheat

and barley fields are not controlled for in the survey results. Finally, many farmers produce barley because it is an important source of feed for their livestock.

Several principal conclusions can be drawn from the study. Study results imply that barley and wheat enterprises in the Mafraq area do not differ between farm size, farmer strategy or precipitation zone. Research scientists may treat wheat and barley enterprises as homogenous units in analyzing and making recommendations with regard to current farm practices. Current barley and wheat enterprises are profitable in the short run in a year with average crop production.

d) Statistical Analysis of Farmer Livestock Survey Data in the Mafraq Barley Cropping Region of Northeastern Jordan. David W. Hughes

The emphasis here is on identifying and describing principal types of livestock operations (flock types) in the Mafraq area of Northeastern Jordan through statistical analysis of survey data acquired in the region in 1988 and 1989. Also examined are the reasons for differences in animal productivity between various farms.

Flock types are distinguished by composition of sheep and goats, geographic location, flock size and quality of diet. Statistical relationships are established between indicators of flock productivity and characteristics of the flock with an emphasis on the relationship between productivity and the amount of high quality feed inputs. The statistical relationships are used in constructing livestock enterprise budgets for typical farm operations in the Mafraq region.

Flocks were classified as goats-only flocks, a mixture of sheep and goats, and predominately sheep (i.e., at least 90 percent of the flock is sheep). The division in flock types is constructed partly to account for higher milk production by goats as compared to sheep. ANOVA analysis of the survey data determined that goat and mixed flocks were more productive than sheep flocks. Attempts to explain the difference in productivity between flock types were largely unsuccessful.

Flock types tended to follow a geographic pattern with goats concentrated in the western (wetter) portion of the Mafraq region. Mixed flocks and sheep flocks tend to be concentrated in the drier central and eastern zones.

The productivity of the livestock flocks is examined both in terms of milk production and total productivity. Total productivity is the total value of milk and young stock produced per head. Total production equals the number of lambs and kids produced, multiplied by their average selling prices plus all milk production valued at an average selling price.

Both total value of production per head of sheep and goats and milk production per head are related to feed energy intake per head, area of cropland seeded to cereal grains per head and total costs of purchased inputs per head. Linear, log-linear and non-

linear exponential functional forms were used in examining the relationship between total productivity and milk productivity and these independent variables.

Milk productivity per head is regressed against energy content of hand-fed feeds per head (EPH) and winter cereal area per head (WCH) in a multiple linear regression. The coefficient of EPH is highly significant (t value of 2.9, confidence level = 0.995) while WCH is somewhat significant at a lower level of confidence. Overall fit tends to be fairly good for all the flock types, with $R^2$ varying from .24 for sheep flocks to .41 for mixed goat and sheep flocks. Including cash expenditures per head as an independent variable improved the goodness of fit for the multiple linear equation.

The relationship between total productivity per head (TPH) and energy per head (EPH) is the strongest under the exponential functional form (r value of .67). TPH is also regressed against total costs (TCH) and winter cereal area (WCH) per head as well as EPH. The exponential functional form provides the best fit. The total productivity of the ewe or doe increases at an increasing rate as total feed energy per head increases (marginal productivity is increasing) under the exponential functional form. Apparently, livestock production in Mafraq is now in stage I of the production function. Marginal productivity per head would be expected to eventually show constant and then decreasing returns to larger amounts of high quality feed inputs.

In conclusion, in the Mafraq region, goat-only and mixed flocks tend to be more productive than sheep-only flocks. Animal productivity is influenced by level of high quality hand feeds as well as by expenditure per animal unit and area of winter cereal per head. Increasing the level of high quality feed inputs would apparently lead to significant increases in animal productivity.

e) Costs of Producing Livestock for Dryland Farms in the Mafraq Region of Northeastern Jordan. David W. Hughes

This case study is based on livestock budgets and profitability analyses for the different farm flock types in the Mafraq dryland farming region of northeastern Jordan. The budgets are based on farmer surveys conducted in the Mafraq region in the 1988 and 1989 crop years.

Budgets, total returns, and net profitability analyses were calculated for three typical flock types:

1) a goat flock of 35-breeding females (does);
2) a mixed flock of 75 breeding females including 50 sheep (ewes) and 25 goats (does);
3) a sheep flock of 155-breeding females (ewes).

A major component of farm livestock costs were own-farm and purchased feed inputs. All flocks were assumed to follow the same feeding regime of straw, grains and

wheat bran. Seventy percent of barley grain and 37 percent of barley straw are purchased while the remainder comes from own-farm production.

Total costs vary from 40.15 JD (Jordan Dinar) per breeding female for the goat flock to 32.97 JD per breeding female for the mixed flock. Differences in total costs between the three flock types are largely explained by differences in the amount of labor required per head. For all flock types, cash expenditures constitute, at most, only about one-half as much as own supplied inputs.

Returns from animal production partly stemmed from the selling and home consumption of milk products and hair and wool products. The majority of returns from animal production came from the sale of lambs and kids. Birth rates (number of surviving lambs and kids per adult female) range from 1.0 for the goat flock to 0.59 for the typical sheep flock.

Total returns vary from 54.93 JD per head for the goat flock to 41.81 JD per head for the sheep flock. Differences in total returns between the two flock types are explained by the higher milk production and higher birth rates of the goat flock. Net returns to land, management and capital range from 14.78 JD per head for the goat flock to 9.20 JD per head for the sheep flock.

The principal conclusion from the case study is that all three flock types in the Mafraq area are profitable in the short run.

### f) General Conclusions From Jordan Case Studies

These analyses indicate that current livestock and enterprise operations in the Mafraq area are profitable in the short run in years when crop production occurs under average conditions. Improved feeding regimes have the potential for increasing livestock productivity and enhancing farm income. Farmers' ability to implement improved feeding regimes are dependent, however, on their ability to increase crop production through the adoption of yield-enhancing technologies such as barley-vetch crop rotations.

Long run analysis implies that current farm productivity will decline in the future if soil resource conserving technologies are not adopted. Technologies such as the introduction of fertilizers, incorporation of some crop residues, and vetch-barley crop rotations have the potential for improving and maintaining the soil resource. An improved soil resource would enable crops to take better advantage of the precipitation that the area receives.

Conditions found in the Mafraq area are very similar to those found throughout the Middle East and North Africa. Combined crop/livestock (sheep and goats) farming systems are also common throughout these regions. Technologies that are successfully adopted in the Mafraq area are likely candidates for improving the productivity and sustainability of farming in other areas with similar conditions.

Analysis of a strategy that farmers use--grazing a barley crop in lieu of its harvest--reduces the variability of income and may even slightly increase long-run average income. More extensive risk analysis of farming practices in the region is underway.

Common property steppe grazing land is an important source of livestock feed in the Mafraq region both for local farmers and migratory herdsmen. Ability of the area to sustain current and possibly increased livestock numbers depends to a large degree on the maintenance of the grazing land resource. Future research should include aggregate analysis to indicate possible pressures on the sustainability of grazing resources.

### 4. Burkina Faso Case Study

In this case study the Soil Erosion Control Under Risky Environment (SECURE) simulation methodology was used. The objective of the study was to examine the important effects of labor constraints, minimum family consumption requirements, and risk on farmers's choice of crop mix and tillage/planting methods in the Boromo region of Burkina Faso (northern Guinean/southern Sudanic agroclimatic zone) in West Africa with roughly 850-1050 mm of average annual rainfall. (Description of model is at Section III., Part B., p. 18 and data at Section III., Part D., pp 22-23).

The unit of analysis was a typical dryland farm with the following characteristics: Alfisols soils, farm size of 8 hectares (1.2 Ha low slope and 6.8 mid slope); family size of 17 members, farm workers 10 (full time equivalent); crops - sorghum, millet, groundnut, maize, rice, vegetables, cowpea, and sorghum-cowpea intercrop; traditional technology with no modern inputs; and home consumption of 160 KG of sorghum and/or millet per family member with possibilities of substitution, 25 KG of maize or rice, 10 KG of vegetables, and 10 KG of groundnut. Risk in this farming situation arises mainly from variability in rainfall and its effect on crop yields and soil loss. The risk parameters employed in the analysis are variability in rainfall (R-factor in the Universal Soil Loss Equation), crop yields, and crop prices. The tillage practices examined are traditional, plowing, and tied ridges. It is noted that these practices enhance long-run productivity by reducing soil loss and hence increasing the soil moisture holding capacity. For example, in case of sorghum and millet plowing and tied ridges increase yields by as much as 22% and 26.4% respectively compared to traditional methods.

The major conclusions of this study are: (1) the effects of risk on the choice of tillage system is significant. As farmers substitute reductions in risk for greater expected income, more of their mid-slope fields are cultivated using tied ridges. This effect is clearly due to the increased soil moisture retained by the tied ridges. (2) The family consumption requirements, which mostly consist of millet or sorghum, limit the amount of maize and groundnut produced to about 10% of the farm area on mid-slope soils. However, even if the consumption constraints are removed, labor constraints force the farmer to allocate about 25% of the mid-slope fields to sorghum-cowpea intercrop, with the remainder in maize.

## 5. Cameroon Case Studies

a) The Impact of Farming Systems Research on Agricultural Productivity: the Case of North Cameroon. D. Ngambeki, R.R. Deuson and J. Lowenberg-DeBoer.

The principal objectives of this case study were to: (1) estimate impacts of the Farming Systems Research program of the Semi-arid Food Grain Research and Development Project of Cameroon (SAFGRAD/FSR) on both traditional farmers and farmers who have already adopted extension recommendations, and (2) indicate how technologies developed by the SAFGRAD/FSR Project could be integrated into existing production systems thereby raising productivity and profitability. The framework is a comparative analysis of production, resource use and income estimates for typical farming systems employing different levels of technology and farm management practices. These estimates have been produced using whole-farm linear programming models. Data for the case study were drawn from the SAFGRAD North Cameroon Farm Trial and Farm Survey Data Base described in Section III., Part D., page 21. The modelling framework employed is described in Section III., Part B., pp 21-22.

The typical farm analyzed in this study is found in the North Province of Cameroon in the Benue area. The farm family is 10 persons operating 5.6 ha. Predominant soils are sandy or crusted, highly eroded with low fertility (37 per cent), or black soils of medium fertility (55 per cent). Rainfall is highly variable between and within seasons with the long-term annual average ranging between 700 and 900 mm. The main traditional food crops are long-season sorghum, millet, maize and cowpea. Cotton is the dominant cash crop while groundnut is both a food and a cash crop. Slash and burn is the method of land clearing, land preparation is with an ox and plough, and chemical fertilizers are used on cotton and on maize in small amounts. No other chemicals are used and weeding is done by hand. Major constraints examined in this study are; declining soil fertility, lack of suitable short-cycle crop varieties, and labor shortages at planting and weeding times.

The analysis involved first construction and verification of (1) a base case farm model where only traditional production practices are followed, (2) a model where Cameroon Extension Service recommendations are added to the list of technology choices, (3) a model that adds SAFGRAD tested practices to model number two, and (4) a model based on traditional plus SAFGRAD options. As indicated above, the modeling framework calls for maximizing net farm income subject to various farm constraints relating to land availability and quality, labor availability by type (hired or family), animal power, minimum family food and net income requirements, and crop rotations/intercropping in relation to timing of operations. Impacts associated with adoption by traditional farmers of either Extension Service recommendations or SAFGRAD technologies pertaining to soil fertility and crop management, and the combined impacts of both Extension and SAFGRAD recommendations are revealed by comparing model solutions.

Extension Service recommendations examined were: shorter cycle varieties of maize, groundnut, cotton, cowpea, and sorghum; improved land preparation, seeding times and rates, plant density and thinning; insecticide and fertilizer applications. SAFGRAD options were: high yielding short-season crop varieties; the use of manure (alone and in combination with nitrogen fertilizer); improved plant density and thinning, seeding times and rates; ploughing and ridging; the use of insecticides; and improved timing of weeding operations.

Results of the study indicate, first, that both the traditional farmer and the farmer that has already adopted the extension technologies can increase their gross margin by 50 percent through adoption of the SAFGRAD/FSR technologies. Second, the way in which resource allocation occurs when the Project technologies are integrated into the base model and the extension model confirm that soil fertility and lack of short-cycle adaptable crop varieties are, indeed, major production constraints. Third, the introduction of a single technology, e.g. an improved maize variety, may not have a significant impact on either the base-model farmer or the extension-model farmer. Albeit sequential adoption of SAFGRAD/FSR technologies is less beneficial than the adoption of a package, it still offers appreciable yield and income increases over those derived from the traditional practices. Fourth, both traditional farmers and those who have already participated in extension programs can adopt SAFGRAD/FSR soil fertility techniques in combination with some of the improved crop varieties and raise productivity and profitability.

b) Integrating Livestock into Farming Systems in Northern Cameroon. D. Ngambeki, R. Deuson and P. Preckel.

Livestock and crop farm systems are major components of agricultural production in the semi-arid zone of West Africa. Nevertheless, the two systems have not yet been combined to any great degree. Even though livestock can benefit the crops as a source of draught power for plowing, planting, weeding and transportation as well as provide manure to replenish badly needed soil nitrogen and organic matter, and crops can provide grain and crop residue for animal feed integration has not generally occurred. Farmers relying on traditional practices do not seem to be able to produce/acquire the feed to maintain animals at all. Mixed crop-livestock systems as do exist cannot support their animals for the whole year and turn them over to momadic herdsmen for care and maintenance during the dry season, thus losing significant animai "benefits". This case study deals with this situation and addresses the question of what factors need to be changed at the farm level in order for better integration of crop and livestock systems to occur. (Model description is at Section III., Part B., page 14, and data base description is at Section III., Part D., page 21-22).

More specifically, the objectives of the study are to: (1) identify and evaluate the benefits of a crop-livestock mixed production system that emphasizes the complementarities associated with an integration of the two major components into one

farming system; (2) formulate a feed management regime that mixed farmers in Northern Cameroon can use to maintain animals on their farm throughout the year; (3) demonstrate the profitability of mixed farming and the sustainability of agricultural production by integrating livestock into crop-based farming systems.

As in the previous case study of Cameroon, this study focusses on the typical farmers of Northern Cameroon in the Benue area and draws upon the same general data base. While the data base is the same, in this case stratifications were different in order to capture the differences between those farmers who keep livestock (in addition to draught animals) and those who do not. A distinction was also made between farmers who put most of their land into cotton, ie., cash crop orientation, and maize-based farming systems. Also, since farm size differences were noted in the stratifications this analysis deals with small and medium crop and/or crop-livestock systems. The representative farm types examined, therefore, are:

| | Farm Size - ha | | | |
|---|---|---|---|---|
| | Cotton-based | | Maize-based | |
| | Small | Medium | Small | Medium |
| With Livestock | 7.0 | 9.1 | 7.3 | 11.6 |
| Without Livestock | 3.9 | 7.3 | 3.8 | 9.3 |

Crop technologies included as options in the analysis are traditional practices plus the SAFGRAD improved recommendations studied earlier. The "mixed" farmer initially is assumed to have an oxen team and 2 cows but no other stock. Options included permit the farmer to purchase additional cows, goats or sheep. In this case study the crop sector provides crop residues to the livestock as a source of feed. However, the farmer can supplement crop residues with purchases of cotton cake, grazing green pasture, grazing stubble, and hay made of grasses harvested from fodder banks. He can also purchase additional animal nutritional supplements. The livestock, in turn, provide manure for soil enrichment as well as traction power.

Evidence seems to indicate that in the study area keeping of animals is limited because of the difficulty of providing feed throughout the year. The key feature of this case study is the inclusion of SAFGRAD crop technologies, which are not as yet widely practiced, along with traditional practices to determine if improved cropping systems would make the difference.

Principal conclusions from the case study are:

1. The results indicate the improvements to the present farming system via the introduction of improved crop technologies and new varieties appear to produce only modest income gains (less than 20%). The income gains associated with the introduction

and integration of livestock are quite large in contrast (nearly a four-fold increase for our small-scale farmer and almost a three-fold increase for the medium-size farmer).

2. In addition, if maize markets can be developed to the point that maize becomes an important cash crop, and maize farmers can get access to fertilizer supplies, then additional gains in the 5-20% range may be achieved.

3. The introduction of improved crop technologies alone, despite its moderate economic gains, is likely to require an increase in the importation of chemical fertilizers, and may not make efficient use of the low fertility fallow and/or marginal land as when combining with organic manure. That is, in the long run, farmers may still face a severe soil fertility constraint. On the other hand, by adopting improved crop technologies together with the integration of crop-livestock, the gains should be sustainable through the efficient feeding and use of livestock by-products.

4. Animals are fed with a combination of grazing stubble and stall feeding of purchased feeds and stored crop residues. The cropping system benefits from the use of animals for draught power, and soil fertility is maintained through the application of animal manure supplemented by smaller amounts of chemical fertilizers. The challenge to the research and extension system will be to raise the level of farmers management skills, since only through good management will the system sustain itself.

5. From a policy perspective, the path to improving farmer incomes is clear. By introducing strong research and extension programs focused on the integration of livestock and cropping systems, substantial gains can be made toward developing a sustainable, more productive agricultural sector in Northern Cameroon. Additional gains may also be achieved via the development of markets for alternative crops, by increased access to improved maize and cowpea seeds, and by improving access to fertilizer. However, the largest gains by far appear to be from education of farmers regarding the necessary practices and benefits of an integrated crop/livestock production system.

c) Analysis of the Effects of New Agricultural Technologies in Northern Cameroon: A Risk Perspective. (Draft) E. Loehman, D. Ngambeki, Z. Yu and R. Dason

As in the previous study, the purpose of this analysis is to evaluate and compare Cameroon Extension Service recommended production practices and SAFGRAD/FSR recommendations in relation to traditional practices. Here, however, the effects of different rainfall regimes on crop yield and of farmer attitudes toward yield and income variability is explicitly taken into account.

The North Cameroon Data Base (Section III., Part d., page 21-22) is again the source of information for this study, but farms are now additionally stratified into three weather classifications, dry, intermediate, and wet, based on daily rainfall records over 23 years. Two generally contrasting weather regimes were then defined (dry and wet) and probabilities for dry, intermediate and wet years within each were calculated. Statistical

parameters for crop yields were then estimated for each weather state, type and level of technology, soil type, and plant date. Traditional long-season cultivars as well as short-season varieties were examined along with chemical fertilizers, manure, ridging, tied-ridges, insecticides, and plant density.

While the farm modelling framework is similar to that of the previous study the focus on weather states and related probabilities means that a set of models has been developed for each of two farming systems, viz., the dry weather system and the wet weather system (see Section III., Part B., page 15). Within each system specific whole-farm models are developed, as before, for the traditional, Extension Service, and SAFGRAD/FRS situations. Also, objective functions now include yield probabilities and Pratt-Arrow risk aversion coefficients with the maximand now expected utility. Since farm data was stratified by agro-climatic zone for this study, input-output coefficients differ somewhat from those of the previous study. Thus, family size is 5, farm size is 4 ha. and family food and minimum net income requirements are reduced. Finally, in order to focus primarily on the difference weather makes on farm planning, soil type was held constant across all models. In all other respects the models are the same, i.e., technologies and farm management options, such as planting dates, have not been altered.

General results of the analysis show that new technologies can significantly improve farm production and income in ways sensitive to farmers attitudes about risk.

The most dramatic effect of new technologies would be to reduce the disparity of income across weather conditions in each of the two climatic regimes studied. Remarkably, new technologies would permit the same optimal cropping pattern in both the wetter and the dryer regimes. Moreover, introduction of new varieties, tie-ridges and corresponding optimal plant densities and planting dates can lead to a reduction in use of fertilizer and other chemicals which are often difficult to obtain and costly. In the drier regime new technology permits the farmer to satisfy the desired minimum net income constraint, whereas this was not possible with traditional technologies. In wet regimes, highly risk averse farmers could increase net income by 107 percent, 44 percent, and 20 percent respectively during dry, intermediate or wet years by adopting improved technology and management practices. Within dry climatic regimes the percentage increases are, 138, 65, and 31. Preliminary analysis tends to indicate that reducing the level of farmer risk aversion across these climatic and weather conditions does not have a significant effect on optimal production plans.

**NEED TO BRING IN EFFECT OF USING RISK ANALYSIS APPROACH COMPARED TO "IMPACT" STUDY ALTHOUGH THE COEFFICIENTS FOR MODELS ARE NOT THE SAME DUE DIFFERENT STRATIFICATION OF FARMS**

### d) General Conclusions from Cameroon Case Studies

To be completed

### 6. Benin Case Studies

Study finished. Write-up not completed -- waiting for Manahil's Thesis to arrive.

## IV. Work In Progress

The TSMM/EC program at Purdue University has largely been placed on hold pending new developments associated with a follow-on project. In the fall of 1989 it became apparent that Dr. Deuson, PI, would very likely be leaving the University before the year was out for another assignment. We then limited our work to completion of ongoing effort with no new starts. In January Dr.Deuson accepted a new position as Chief-of-Party for a Purdue-WINROCK-AID bilateral assistance farming systems research project in Burkina Faso. By the end of the fiscal year all work at Purdue was completed with the exception, as indicated above, of only the Benin work and some editing to a case study on risk using the Cameroon data base. We expect both of these activities to be finished in several weeks. We also expect to establish a long term joint program of work with Dr. Dueson's project and discussions laying the groundwork for that are underway. The Burkina Faso household-farming systems study begun at WSU is already a step in that direction.

At Washington State we have expanded our staff with the hiring of one additional French speaking post-doc for, at this point, a short-term assignment. We hope to be able to extend this appointment once the TSMM follow-on project is in place. The Project has also acquired two new Ph.D students, for a total of three, who are now ready to commence full-time work on their dissertations. The Jordan farm level studies which WSU is carrying out are nearing completion. This fact, plus the new staff, allow us to begin some things not heretofore possible. One of these is the collaboration with Dr. Deuson's group in Burkina and the University of Oagadougou in scheduled farm-surveys leading to the household studies. Another is tapping into a data set brought to Pullman by a Sudanese student. Continuing the Jordan work would be desirable on grounds of continuity and payoff to investment so far, but is very unlikely given the Middle East political situation. Given the real possibility of a productive cross-project involvement in Burkina, and the previous level of effort in Niger, Cameroon, Benin, and Mali such a focus makes good sense.

The work underway at WSU and ERS, therefore, comprises the bulk of activity in progress at this time. The principal aspects of this work are: completion of the EPIC adaptations for wheat and barley, and farm modeling in Jordan; review of methodologies for measuring aggregate effects of technology change; field surveys in Burkina Faso and development of a household component of a whole-farm model; formulation of a dynamic model of long-term time path in production, land conditions, and bush-fallow systems in Sudan; data base work (Jordan, Sudan, and Burkina data); completion of Jordan case studies; and, some extensions of the Mali work done earlier.

## V. Most Significant Accomplishments To Date

General areas where it is felt the project has made significant accomplishments are: (details on each area to be completed)

1. The creation of a closely knit and highly productive core staff from among three separate institutions. Thirty-one faculty, senior researchers, and graduate students have been involved to-date. This group, plus the many others with whom working relationships have been established, form a strong network and cadre of specialists which can be drawn upon in in the future to support AID's program.

2. Work involving the adaptation of complex crop-growth and soil water-balance modeling for practical application to agricultural problems in critical priority locations. In this regard, efforts to establish linkages with physical scientists, eg., soils experts, agronomists, agricultural engineers, and agroclimatologists, by TSMM/EC staff are highly laudable and deserving of recognition. It was these sincere attempts to involve others in a truly multidisciplinary way that gives TSMM its unique character among S&T projects. The collaboration with scientists at ARS, ICRISAT/ Sahelian Center, ICARDA, and Jordan University of Science and Technology proved particularly rewarding and has resulted in a strong interdisciplinary network of dryland agricultural experts.

3. Better integration of agronomic, agro-climatic, and economic relationships in rigorous analysis of farm production technology appraisals.

4. Case study analyses and information dissemination pertaining to a wide range of alternative technologies and farm management practices in several agro-climatic zones using comparable methodologies.

5. Data base development

An area where less than expected results were obtained has to do with analyses at a more aggregate level than the farm. Although a major macro level policy analysis effort was never planned for TSMM/EC, some activity along these lines was anticipated as follow-on work to the more micro modelling and country case studies as this was completed. Unfortunately, a "scaling back" of the program at Purdue beginning in October, 1990 due to budget cuts and to the departure of Dr. Deuson precluded a start in this direction at that institution. At the same time some initial work at Washington State was postponed because of delays associated with the EPIC crop growth model we were working with there. Previously planned review of literature on appropriate methodology

as the necessary first step is now scheduled for the latter part of FY 1991 at Washington State University.

## VI. Life-of-Project Report Outputs (to date)

### FY 1987

**Publications and Presentations**

**A. Papers Published**

None

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