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USE, CONSTRUCTION, AND DOCUMENTATION OF THE WHOLE-FARM PLANNING MODEL FOR WEST AFRICA (WFPMWA)

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I. INTRODUCTION AND OVERVIEW

The USAID sponsored project Technology for Soil and Moisture Management (TSMM) focuses on dryland agriculture in West Africa and the Middle East. TSMM economists seek to identify cropping patterns, land-use practices, and policies that will be not only attractive to farmers in the short run, but also will conserve soil resources and sustain productivity for an indefinite period of time. Mathematical whole-farm planning models greatly facilitate the process of identifying desirable land-use practices in developing agriculture.

This paper is related to the construction and use of a whole-farm planning model for West Africa (WFPMWA) as specifically applies to the Kita region in Mali. It is designed to facilitate use of the WFPMWA developed by researchers at the Department of Agricultural Economics, Washington State University and researchers at the Economic Research Service of the U.S. Department of Agriculture. The paper can also serve as an example of how to document use and construction of a mathematical programming model in a spreadsheet environment.

A LOTUS 1-2-3 spreadsheet is used to generate the WFPMWA, which is a mathematical programming model in a MPSX format that can be run immediately on LINDO and with a few adjustments on MPSX or on MINOS. All important coefficients in the "MPSX section" of the spreadsheet are functions of tabled values in other portions of the spreadsheet. This construction allows the model user to make relatively quick and easy changes on large components of the mathematical programming matrix by changing values in the tabled portion of the worksheet.

The paper consists of three main sections other than the introduction and overview.

First, an actual application of the model is discussed using an overview of the need for and problems associated with the adoption of moisture and soil

conserving technologies in the Kita region of Mali. Included in the section are a general description of dryland farming in Mali, the economics of soil and moisture management in the region, and an examination of technologies with the potential for increasing crop production and resource productivity in West Africa. Also included in the section is a brief discussion of the model's structure. The model is then used to evaluate the potential for the adoption of yield enhancing technologies for a typical farm in the Kita region of Mali. Results are examined for a variety of farm scenarios, including varying assumptions about farm size, about farmer perceptions of production risk and subsistence needs, and about the effect of soil erosion on future crop production.

Next, a users guide is presented, where actual use of the WFPMWA is facilitated by, for example, giving the location in the LOTUS 1-2-3 spreadsheet of various components of the model. The users guide section also contains an explanation of the variable naming scheme used in the model. Further, an explanation is given concerning how changes in the table section of the spreadsheet can be used to implement changes in the mathematical programming model. Finally, an explanation is made of how to generate the programming model for solution in LINDO or other relevant software from the LOTUS 1-2-3 spreadsheet.

Third, a model documentation section includes a detailed discussion of the model's structure as well as documentation of data sources used in building the model. One salient feature of the model is a safety-first food needs constraint used in representing farmer concern about production risk. In this regard, a discussion is included concerning the use of a water balance crop growth model in estimating crop yields under average weather conditions and under a "worst-

case" situation where farmer concerns about risk are predominant. Another important model feature is an accounting of the effects of current erosion on future farm income in the model's objective function.

II. ACTUAL APPLICATION OF THE MODEL AND PROBLEM OVERVIEW

Introduction

In many developing countries, pressure of food needs for growing populations has led to increased reliance on dryland crop production from lands that are inherently low in productivity due to low rainfall and low levels of soil fertility. This condition is especially common in the Sudanean and Sahellian zones of West Africa. Often, these lands are also subject to wide variation in yield from one year to the next and to deterioration over time due to erosion and loss of basic soil nutrients. Because of low yield per unit of land area, traditional methods of cultivation that use large labor input per unit of land result in low marginal productivity of labor and low levels of living for farm families. Even more discouraging is the fact that productivity and level of income are declining rather than improving.

One opportunity for improving the situation of these societies is through improved soil and moisture management. In this report, cropping sequences and farming practices that enhance fertility, reduce the rate of soil erosion, and increase soil moisture through improved rainfall infiltration are examined in the context of whole-farm operation of a typical dryland farmer in Mali, West Africa. For farmers to adopt recommended soil and water management practices, technologies must be both appropriate to the specific physical conditions found on the farm and consistent with the farmer's available resources and income and risk-avoidance objectives.

General Background: Dryland Farming in Mali

Agriculture in Mali is oriented to staple food production. Eighty-five percent of all cultivated land is in food grains, primarily sorghum, millet, maize, and rice. Yet, from 1966 to 1983, total food production in Mali declined at a rate of .5 percent per year (Shapouri et al., 1986). With a projected annual growth rate of 3 percent, resulting in a doubling of the population in 25 years, the future ability of Malian agriculture to feed its population is in question.

Soil moisture is a primary determinant of crop production in Mali with 90 percent of all arable land farmed under strictly rainfed conditions. Most of the crop population is in the 40 percent of the country where rainfall averages from 400mm to 1400mm. Throughout the area, rainfall is highly variable in timing of onset of the summer rains, in length of the summer rain season, and in the amount of rainfall that occurs. Thus, there is considerable uncertainty connected with agricultural production and with the returns to new technologies or investment in agricultural improvements that may be sensitive to moisture conditions.

Exacerbating the rainfall situation in Mali is the generally poor quality of soil resources. Crusting and sealing of the soil is a widespread problem. Natural moisture infiltration is poor due to the combination of high rainfall intensity and low absorptive capacity of the soils. In addition, the natural fertility of soils is low; organic matter is lacking and soils are deficient in nitrogen, phosphorous, and sulfur.

Land fertility and productivity are declining at both the intensive and extensive margins (Lallement, 1986). Fertilizer and manure applications are too small to replace nutrients withdrawn through crop growth, and the long rejuvenating bush fallow is being greatly shortened or eliminated in many cases.

Erosion of topsoil and failure to return organic matter to the soil contributes further to deterioration of soils. Limited potential for major productivity increases or area expansion in the small irrigated sector (Eicher, 1986) suggests that measures must be adopted at the farm level that will enable low-resource dryland farmers to improvement management of available land and water resources (Stewart et al., 1986).

Economics of Soil and Moisture Management

Soil and moisture management technologies produce economic values for the farmer in several ways. First, the technologies improve infiltration and increase moisture storage in the root zone where it an be utilized by the crop. In marginal dryland areas, increased soil moisture has a direct effect upon yields during the cropping season in which the practice is applied. Increased infiltration of water also reduces the movement of water over the soil surface thereby reducing yield damage due to washing out or silting over of plants. Second, the erosion of soil that is caused by surface run-off has a long-run effect through loss of the productive topsoil layer.

The economic analysis of the immediate effects of improved soil and moisture management would include a benefit-cost analysis comparing the value of increased yield to the cost of adopting the alternative management technology. Marginal analysis of increase in yield from alternative levels of application of the technology would also be appropriate.

The long-run productivity gains (productivity losses averted) are a return to investment in improved soil and moisture management and erosion prevention. Economic analysis of long-run productivity effects requires first a determination of the effect that the soil and moisture management technologies will have on the rate of erosion. Next, the relationship between rate of erosion and productivity

of the land must be determined. The given amount of erosion causes a permanent, for all practical purposes, deterioration in the productivity of the soil. Thus, crop production in the season imposes a cost in a form of reduced productivity that extends indefinitely into the future. The value of that cost stream is the appropriate measure of the productivity costs of erosion, and the present value of the stream of changes in future productivity is the relevant measure of the soil conservation contribution of an improved soil and moisture management technology.

The most straightforward way to evaluate the benefit of soil erosion avoided is to consider the soil to be an income earning asset. Current decisions about the use of soil conserving practices depend upon the value attached to preventing the future loss in productivity of that asset as compared to the costs that must be expended in carrying out the conservation practices. The value of soil conserved and productivity decline averted is the present value of the expected decline in yield over many future years resulting from erosion in the current year. The present value of the future yield decline depends upon the number of years in the planning horizon and the discount rate. Peasant farmers are apt to have a very high discount rate and a short planning horizon because of pressures such as supplying the family's immediate nutritional requirements and generating funds for production and family living expenses. Society may take a much longer view, and employ a much lower discount rate because it recognizes future generations as well as the current generation must be provided for.

Technological Options for Soil/Water Management

A number of recent studies have demonstrated the potential of practices such as animal-traction powered tillage operations, tied-ridging, dikes, and mulching to improve water use and crop yields in dryland environments of Africa

(Delgado and McIntire, 1982; CRED, 1976; Nicou and Charreau, 1985; Roth and Sanders, 1985; Sanders, Nagy and Shapiro, 1985, Roth et al., 1986; Purdue Univ., 1986). These studies, mostly from Burkino Faso, also indicate a positive interactive effect of moisture management technologies and fertilization. The combination of tied ridges and fertilization will increase yield by more than either fertilizer or tied ridges alone. A more assured supply of adequate water to the crops' root zone means higher and more certain production increase from hard earned money spent on commercial fertilizer.

The slow adoption of potential technologies may be explained in part by the farmers' learning curve for "technology packages" and a lack of adequate extension support, and by the cost and unavailability of purchased inputs and equipment maintenance and repair services. Moreover, studies point out that new technologies may have certain characteristics which restrict their adoption on particular farms. Animal traction plowing may accelerate erosion and conflict with labor requirements for planting. Fertilization may be ineffective or even counterproductive without adequate moisture. Tied-ridge construction may increase labor requirements at critical times and may not be successful on all sites. However, the greatest deterrent to the adoption of what appear to be desirable technologies may be a lack of empirical data on the costs and returns associated with new soil/water management practices and a lack of analysis of whether adoption of new soil and water management technologies will contribute to or detract from the family's short and long-run subsistence, income, and stabilization objectives.

The objectives of this research are to: (1) estimate the cost and productivity effects of existing practices and new technologies, given the various soil, rainfall, and other resource conditions of the dryland farmers, and

(2) evaluate the acceptability of alternative farm practices given the subsistence, risk avoidance, and income enhancement goals of typical farmers.

Mali Case Study

A basic pre-condition if improved soil and water management practices are to be widely adopted is that they must be compatible with the farm-level setting in which they are to operate (Matlon and Spencer, 1984). Management practices must be suitable for the particular soils, rainfall patterns, and biological conditions at the farm site. They must be effective in helping the farmer to increase his income and satisfy subsistence, security, and other objectives given the capital and labor resources he has available.

Whole-farm modeling is widely recommended as a useful methodology for appraisal of small-farm technology options (Ghodake and Hardaker, 1981; Nagy, Ames and Ohm, 1985; Roth, Abbott, Sanders and McKenzie, 1986). Crop growth models have also been recommended as a means of modelling farmer reactions to risk by simulating growing conditions under variable weather conditions (Hughes). For these reasons a farm programming model, based on typical farming operations in the Kita region of Western Mali, was designed . Results from a water balance crop growth model, also developed for the analysis, were used in the programming model to evaluate the effect of weather patterns on yields and, hence on the riskiness, of various cropping scenarios. The programming model has a number of features that should make it a useful prototype for analysis in other dryland agricultural areas.

The Farm Planning Model

A linear programming model was designed to reflect the perspective of a farmer seeking to optimize in the face of given production possibilities and limited resources. The general form of the model is

$$\text{Max } I = \sum_i P_i X_i \qquad i = 1, \ldots, n$$

subject to

$$\sum_i X_i \; a_{ij} \leq C_j \qquad j = 1, \ldots, m$$

$$X_i \geq 0$$

where I is the income objective, P_i is the price or revenue per unit of the ith activity, X_i is the level of the ith activity, a_{ij} is the amount of the jth constraint used per unit of ith activity, and C_j is the limit of the jth constraint. (An expanded algebraic version of the model can be found in Appendix 1.)

This programming model considers two objectives that are important to small farmers in the dryland areas of Africa. The first objective is a secure supply of staple food. Farmers are generally seeking to acquire adequate land resources and follow a management program that will have a high probability of meeting their family's basic supply of food requirements under any adverse weather conditions. The safety criterion in the model is a constraint that the optimal farm plan must contain activities that will provide minimum food requirements even in a year with weather such that a higher crop yield would be expected in about nine years out of ten.

The second objective is to maximize profit, subject to the safe minimum food supply constraint. This arrangement is consistent with the "safety first" rules for decision making under conditions of uncertainty (Robinson, et al., 1984).

The food producing, and income-generating, activities in the model include sorghum, millet, maize, groundnuts, and vegetables. Alternative planting schedules for the crops permit an evaluation of interaction between the timing of moisture requirements for the plant and susceptibility to moisture stress

during the growth of the plant with the timing of rainfall and moisture availability. Shifting of planting dates can also help to fit farm operations in line with the availability of labor.

Methods of cultivation include traditional cultivation with human labor only and oxen cultivation. There is an option in either method of cultivation to fertilize the crop or to leave it unfertilized.

The constraints on the cropping activities include land, which is limited in the typical farm case to eight hectares, family labor, and temporary labor available for hire. Oxen labor of 104 hours per month is available if the fixed cost of owning and caring for the oxen has been included. Maintenance of the oxen requires labor and feed supply throughout the year.

The model has a section that accounts for the disposition and use of grain and fodder produced by the cropping activities. The family's staple food requirement, measured in Kcal of energy requirement per year, must be supplied out of the crop production. Dietary diversity restrictions require a variety of grains to meet the family's requirement. Grain must be supplied to the oxen during heavy working seasons and at times of the year when the fodder supply is not adequate for maintenance. Additional grain over and above the family's living requirements and the requirements of livestock may be sold at the market price.

Soil and Moisture Conservation Technology

There are no definitive data for several conservation technologies. However, there is a growing body of information about the technique of "tied ridges". Field data reported from Burkina Faso indicate increases in yields from tied ridging alone in the range of 15-40 percent (Roth, et. al.). When tied ridges were combined with fertilization, the increase in yield was in the

neighborhood of 100 percent over the control plot with traditional farming methods. The advantage of tied ridging is that it retains the moisture and thus not only lowers moisture stress but also creates a situation in which there is more productivity gain from fertilizer applied to the crop. Tied ridges also cut off the surface flow of water and reduce erosion, decreasing the adverse impacts on future productivity. In this analysis, the effect of tied ridges is represented through the increase in the infiltration efficiency and reduction in the annual rate of erosion. Tied ridging does have the drawback of being very labor intensive, however, as discussed in page 7.

Results

The optimal plan for the 8 hectare farm with all parameters and variables at baseline expected values are presented in the first column of Table 1. The profit maximizing plan calls for most of the cropland to be used to produce millet and maize. Long-run average expected yields are used as the basis for optimization. However, even a yield low enough to be expected only one year out of eight would provide more than enough grain to meet the minimum safety subsistence standard. Grain surplus above subsistence requirements is expected to average 7,000 kg per year. If the entire surplus is sold at market price, net income of the farm is expected to be 512,000 Mali francs (MF).

It would be profitable, and contribute to food security, if tied-ridging technology was used on all of the grain cropland, assuming that the expected 25 percent increase in yield can be realized. Because of the tied ridges, erosion is expected to average less than 8 tons per hectare per year. It is indicated to be profitable to fertilize about two-thirds of the grain crop.

Despite having five adult family workers, it is necessary to hire temporary labor during the mid-season periods when weeding, cultivation, and construction

Table 1. Key Results for Kita Area Whole-Farm Model Under Baseline and Alternative Model Scenarios

Scenario	Baseline	B[1]	C[2]
SITUATION			
Farm Size (ha)	8	8	8
Tied Ridges Yield Ratio	1.25	1	1
Present Value Soil Loss (1000 mf/mt)	0	0	1.3
Subsistence Constraint (1000 kcal)	11.2	11.2	11.2
LAND USE			
Sorghum	0.38	0.48	0.48
MIllet	4.15	5.12	5.14
Maize	2.89	0.89	1.74
Groundnuts	0.10	1.02	0.17
Vegetables	0.48	0.48	0.48
Fallow			
TECHNOLOGY USE (ha)			
Tied Ridges	7.42	0	7.36
Fertilized	4.53	6.62	5.62
CROP OUTPUT (kg)			
Sorghum	480	480	480
Millet	5429	4973	5376
Maize	4170	1034	1988
Groundnuts	120	1182	201
EROSION			
Gross (tons/ha)	7.75	35.81	7.81
Pres. Value of Prod. Loss (mf)	0	0	83630
INCOME (mf)	512,071	410,863	332,359

[1]Under scenario B, tied ridges do not increase yields.

[2]Under scenario C, tied ridges do not increase yields and value of future productivity loss from current erosion is not accounted for.

Table 2. Key Results for Kita Area Whole-Farm Model, Under Reduced (5 Hectares) Farm Size, for Both Baseline and Alternative Model Scenarios.

	D[1]	E[2]	F[3]	G[3]
SITUATION				
Farm Size[4] (ha)	5	5	5	5
Tied Ridges Yield Ratio	1.25	1	1	1
Present Value Soil Loss (1000 mf/mt)	0	1.3	1.3	.3
Subsistence Constraint (1000 kcal)	11.2	11.2	10	9
LAND USE				
Sorghum	1.23	3.51	2.23	2.21
Millet	1.43	0.55	0.55	0.45
Maize	1.76	0.35	1.63	1.76
Groundnuts	0.10	0.11	0.11	0.10
Vegetables	0.48	0.48	0.48	0.48
Fallow				
TECHNOLOGY USE (ha)				
Tied Ridges	4.42	4.41	4.41	4.42
Fertilized	1.43	0	0	1.81
Animal Traction				
CROP OUTPUT (kg)				
Sorghum	1347	3090	1966	2107
Millet	1897	480	480	480
Maize	2545	405	1884	2036
Groundnuts	120	120	120	120
EROSION				
Gross (tons/ha)	7.09	6.25	6.86	6.86
Pres. Value of Prod loss (mf)	0	41448	45638	45747
INCOME (mf)	252,315	80,542	121,409	142,726

[1]Under scenario D, the value of future productivity loss from current erosion is not accounted for.

[2]Under scenario E, tied ridges do not increase yields.

[3]Under scenarios F & G, tied ridges do not increase yields and the subsistence constraint is relaxed relative to the baseline level.

[4]Arable farm land is reduced from baseline 8 hectares to 5 hectares under scenarios D, E, F, and G.

of tied-ridges is at a peak. Had temporary labor not been available, the farm plan would of necessity have been changed to reduce labor demands during the peak seasons.

The baseline solution for the smaller 5-hectare farm is similar, but much less surplus grain would be available on average (Table 2). Some rearrangement of the production plan is necessary to insure that subsistence requirements will be met even in a bad crop year. Providing one more kilogram of subsistence safety margin would reduce net income by about 6MF, and probably reduce the long-run average grain production of the farm.

The results of parametric variation on the subsistence safety requirement (Table 2) indicate how important that constraint is to the small landholder with a large family to be fed. In solution F the safety first condition is relaxed by 10 percent. Instead of being willing to accept no more than one-eighth chance of not meeting their subsistence requirements out of their crop (solution E), they are hypothesized to be willing to accept an equal chance of meeting only 90 percent of their requirements. The result is freedom to reorganize production so as to increase by 440kg their average salable surplus of grain and increase by 40,000MF average net income (as compared to solution E). Further relaxing the subsistence safety requirement (solution G) would allow a further increase in expected value of grain production and net income.

Another series of analyses explored the effect of increased consideration of the present value of future productivity lost due to erosion during the current year of farming. Tied-ridges are assumed to give no increase in current yield in these solutions, so there is no reason to employ the slightly more expensive technique other than to protect the land from long-term productivity decline. When no value is attached to soil lost (solution B, Table 1), income

in the profit maximizing plan is expected to average 411,000MF per year, but soil erosion averages 36 tons per acre per year. If the soil loss is considered to have a value equal only to the present value, at a discount rate of 9 percent, of the erosion-caused productivity losses incurred during the next five years, a change to tied ridges would be profitable as shown in solution C. Net income in the current year would decline by about 20 percent (comparing solution B to C), but the savings in future productivity losses averaged would be very large, even if valued at the above conservative basis.

Conclusions

The complexities of interactions between soil and moisture management technologies, resource limitations, and multiple objectives of typical dryland farmers are sufficient to make whole-farm analysis a preferred analytical approach. Even relatively simple yield-weather simulation approaches can be helpful in translating weather data into estimates of the expected distribution of yields over a long series of weather years.

In the relatively high rainfall Kita study area, tied ridges area promising technology if the yield gains reported in field experiments in similar areas can be obtained by farmers in their own fields.

Even moderate consideration of the apparently large erosion-caused losses in future soil productivity would be sufficient to induce adoption of tied ridges or other soil conserving technologies even though there were no immediate yield gains to be realized.

Extension of the model to include livestock enterprises, other soil and moisture conserving technologies and additional crop management alternatives would be appropriate. Better delineation of interaction with and reaction to weather conditions as they emerge during the cropping season should be added to

the model. Estimation for regions with lower rainfall and more moisture stress should proceed.

III. USERS GUIDE FOR GENERATING MATRIX (WFPMWA)

A. Introduction

The users guide portion of this document is intended to aid in the creation of different versions of the Whole Farm Planning Model for West Africa (WFPMWA). The WFPMWA is formulated as a linear programming or mixed integer programming problem which can be solved in either LINDO, MPSX, or MINOS. The model is created in a LOTUS 1-2-3 spreadsheet. The general structure of the LOTUS 1-2-3 worksheet (WFPMWA.WK1) is shown in Figure 1. The worksheet is divided into three major sections: 1) the worksheet directory which extends over the range A1 through F20 (range A1..F20); 2) the MPSX format/print file section (range A22..F5055); and 3) the tables section (range G150..J503). The directory shows the location of key parts of WFPMWA.WK1. The MPSX format/print file section is the portion of the file that is ultimately solved as a programming problem. The table section is used to generate values for key variables in the MPSX format/print file section.

The users guide is divided into four sections: first, programming structure of WFPMWA, second, MPSX format and variable naming scheme for WFPMWA, third, using LOTUS 1-2-3 to generate new values for key variables in WFPMWA, and fourth, creating a LOTUS.PRN file to run on LINDO or MPSX.

B. Model Structure

The general mathematical structure of the programming model is shown in Figure 2. The objective is to maximize net farm income. The matrix is divided into two groups of constraint rows (a. inputs for production, and b. food and feed balance equations) and three groups of columns (a. crop production

Figure 1. WFPMWA.WK1 (Worksheet)

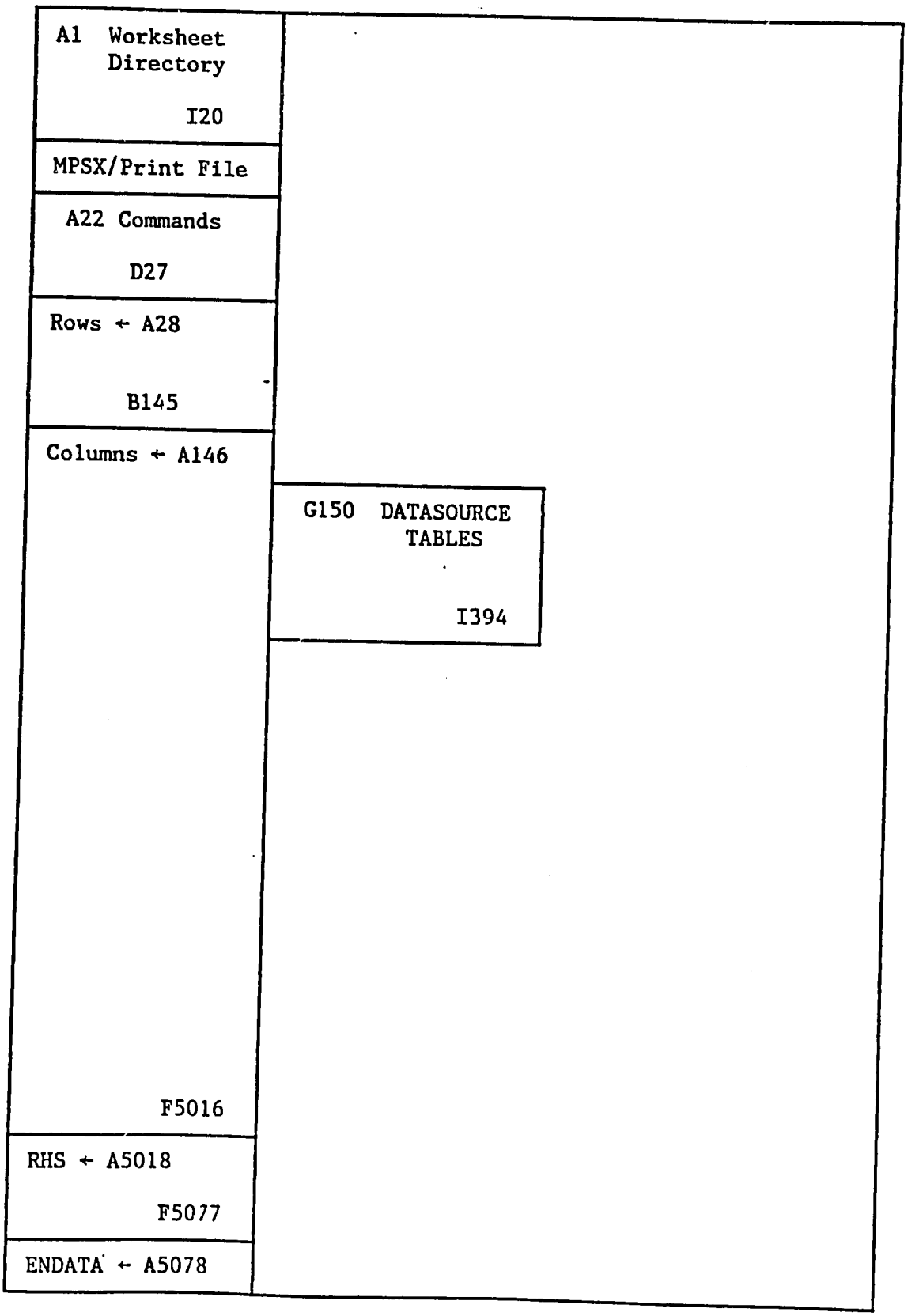

Figure 1, continued.

Activity	Name	Range
Long Season Crops		A149..F2547
Schedule 1 Sorghum		A149..F446
No Fertilizer:		
Base	S10NLHXX	A149..F168
Ox Plow	S10NLPXX	A169..F190
Tied Ridges	S10TLHXX	A191..F210
Ox Plow & Ridges	S10TLPXX	A211..F232
Fertilizer:		
Base	S11NLHXX	A233..F253
Ox Plow	S11NLPXX	A254..F276
Tied Ridges	S11TLHXX	A277..F297
Ox Plow & Ridges	S11TLPXX	A298..F320
Total Oxen Use:		
Base	S10NLAXX	A321..F351
Tied Ridges	S10TLAXX	A352..F382
Fertilizer	S11NLAXX	A383..F414
Fert. & Ridges	S11TLAXX	A415..F446
Schd. 2 Sorghum		A447..F732
Schd. 3 Sorghum		A733..F1006
Schd. 1 Millet		A1007..F1304
Schd. 2 Millet		A1305..F1590
Schd. 3 Millet		A1591..F1864
Schd. 2 Maize		A1865..F1961
Schd. 3 Maize		A1961..F2057
Schd. 2 Grdnuts		A2058..F2188
Schd. 3 Grdnuts		A2189..F2319
Schd. 4 Grdnuts		A2320..F2450
Schd. 3 Veg.		A2451..F2499
Schd. 4 Veg.		A2500..F2547
Short Season Crops		A2548..F4536
Schd.. 1 Sorghum		A2548..F2797
Schd. 2 Sorghum		A2798..F3035
Schd. 3 Sorghum		A3036..F3261
Schd. 1 Millet		A3262..F3511
Schd. 2 Millet		A3512..F3749
Schd. 3 Millet		A3750..F3975
Schd. 2 Maize		A3976..F4173
Schd. 3 Maize		A4174..F4371
Schd. 2 Grdnuts		A4372..F4426
Schd. 3 Grdnuts		A4427..F4481
Schd. 4 Grdnuts		A4482..F4536
Schd. 3 Veg.		
Schd. 4 Veg.		
Fallow		A4537..F4540

Figure 2

GENERAL STRUCTURE OF WHOLE FARM LINEAR PROGRAMMING MODEL

Constraints	Activities: Crop Production				Harvest Crops		Consume Grain	Sell Grain	Feed Own Grain	Buy Feed Grain	Hire Labor		Rent Oxen		Own Oxen	Oxen Keep	Erosion Damage	Right Hand Side
Objective function	0	0	-x	-x	0	0	0	x	0	-x	-x	-x	-x	-x	-x	-x	-x	= Income
Land	1	1	1	1														
Erosion	x	x	x	x														≤ Cropland
Own Oxen																	-1	≤ 0
Family Labor 1	x	x	x	x											-1	1		= 0
Family Labor 2	x	x	x	x	x	x					-1							≤ Max
Hired Labor 1												-1						≤ Family Labor
Hired Labor 2											1							≤ Max
Animal Labor 1		x		x								1						≤ Hired Labor
Animal Labor 2		x		x		x							-1			-x		≤ 0
														-1		-x		≤ 0
Field Yield	x	x	x	x	-1	-1												
Food Safety	-x	-x	-x	-x														= 0
Harvested Grain					-1	-1	1	1	1									≤ -Calories Needed
H.H. Consumption							-1											= 0
Supplement Ox Feed									-1	-1								≥ Calories Needed
Fodder Ox Feed					-1	-1										x		≤ 0
																x		≤ 0

activities, b. food and feed disposition, and c. input acquisition). Most rows and columns in Figure 2 correspond to sets of rows or columns in the complete matrix.

1. Activities

a. Crop production activities

The model provides production activities for five crops (sorghum, millet, maize, groundnuts, and vegetables). There are four potential planting schedules (not all are feasible for every crop), two fertilization levels (none and level one), two cultivation approaches (conventional and tied ridges), two varieties (long season and short season), and three labor systems (human labor only, oxen used in preplant tillage only, and oxen used in tillage and cultivation/wedding).

The production activities each require one hectare of cropland. Labor requirements are stated by time period in which operations such as tillage, planting, and weeding take place. Short-season varieties require less labor because of reduced cultivation and weeding requirements during the shorter growing season. Construction of tied ridges and application of fertilizer require additional labor. Activities that use oxen have somewhat reduced labor requirements.

Each crop activity also has a "safe minimum yield" which is the production that will be equalled or exceeded even in the event of relatively rare bad weather. The current model uses yields predicted from weather conditions that would, on average, result in the worst crop growing conditions (i.e., lowest crop yields) over a ten year period as based on 43 years of data recorded at Kita, Mali.

b. Harvest and disposition activities

The yield from crop activities is standing field yield. Harvest activities use human and possibly animal labor to harvest the crop to transport it to the village or compound, and for threshing and storage. Inputs to the activity are mature crop in the field and labor. The outputs are stored grain and fodder. Harvest activities must take place in a specific time period, when the crop is ready for harvest or later if harvest is delayed.

Grain consumption activities transfer grain from the storage accounting rows to the household consumption requirement rows. Grain in storage may also be sold or used for a supplemental feed supply. Feed grain may also be purchased.

c. Input supply activities

Labor may be hired in any time period, subject to constraints that reflect the limited availability of labor during certain initial periods. Oxen renting activities may also be included in those cases where it is feasible.

Owning a team of oxen is a binary integer (OXINTGER) activity, i.e., it must be either 0 or 1). "Oxen keeping", (the OXENKEEP activity) includes maintenance feed, labor, and expenses, and must be in the basis at the same level as the OXINTGER activity, that is at 0 or 1.

In the current model, OXINTGER is an integer activity. The OXENCONS constraint serves to either force (OXENCONS rhs equals one) or prevent (OXENCONS rhs equals zero) the ownership of oxen as part of the solution to WFPMWA.

The erosion damage activity forces the objective function to include the present value of future yield loss due to soil erosion. The ERSNDAMG activity must equal the total amount of erosion; thus, negative impact on income can be reduced by choosing activities that cause lesser amounts of erosion.

2. Objective Function:

The objective function is net farm income. Crop production activities have negative values equal to the cost of purchased inputs. At present, the only purchased input is fertilizer. Harvesting, consuming, and feeding grain are assumed to require no purchased inputs.

The sell grain activities are the only source of income. Grain prices are chosen to reflect the composite of official and local market prices that a producer would typically receive for any salable surplus of grain. Currently, the buy grain option is available only for feed grain. The local market price is assumed to apply for all feed grain purchases.

Labor hiring and ox renting activities have negative objective function values equal to the hourly wage rate or rental rate.

The objective function coefficient for the binary integer OXENKEEP activity includes the fixed costs of owning and using an ox. These fixed costs include the annual costs of investment in the oxen plus the cost of farm implements that are used in plowing, cultivating or weeding with oxen and other purchased inputs, such as medicine, that are required for oxen "maintenance".

The objective function value for the erosion costing activity is the present value of future productivity loss due to erosion of one ton of topsoil. In the current model, the value is calculated from losses expected during five years immediately following the planning year. For any single year, erosion damage is the predicted decline in yields per ton of erosion multiplied by expected crop prices normalized and summed over all crops. The single year value is then discounted and summed over five years at a 9 percent discount rate. Erosion cost is incurred only in the future--therefore, erosion cost must be added back to the

objective function value to determine income that will be realized in the current year.

3. Constraints

a. Production Inputs

(1) Land -- The model has at present a single land constraint. All land use (crop production and a fallow activity) activities require one hectare of land. The right-hand-side value, the total cropland available to the farm, cannot be exceeded by the amount of land use. Future versions of the model may have land divided into more than one class, with associated crop production activities.

(2) Erosion -- The erosion accounting row requires that the sum of erosion from all cropping activities be equaled by an activity that reduces the objective function by the opportunity cost of productivity loss due to the erosion of one ton of topsoil.

(3) Oxen Ownership -- This accounting row serves to limit ox ownership to 0 or 1 as determined by the row's RHS value.

(4) Family Labor -- There are family labor resource constraints, one for each half-month time period from period 07 through period 24. Total hours of labor use by crop production and harvesting activities must not exceed the amount of labor available in each time period. Labor is measured in hours of adult male equivalent. Family labor available for field work in each time period forms the upper bound on this inequality. Labor may be hired to augment the family labor supply and allow expansion of labor-using activities.

(5) Hired Labor -- There is also a constraint on labor hired in each time period. The maximum of the labor hiring activity is limited to the amount that is highly likely to be available locally.

(6) Oxen Labor -- There is an oxen labor constraint row for each time period. Crop production activities that use animal traction for plowing or for plowing and cultivating require ox labor in some time periods. Oxen labor may also be used in harvest operations. Oxen labor use must be balanced by the supply of labor coming either from owned oxen (for which a fixed cost has been paid) or from a rented ox team.

b. Food and Feed Balance Rows

(1) Field Yield -- There is an accounting row for each crop (sorghum, millet, maize, groundnuts, and vegetables, in this version) and each time period in which the crop may be ready for harvest. The yield is for crop standing in the field. The field yield is transferred by harvesting activities to grain in storage. Harvest grain cannot exceed the total field yield.

Field yields in the current version of the linear program are based on weather for the Kita Station in Mali, West Africa. The November 1987 version of John Day's weather/yield spreadsheet (see Appendix 3, Table 1) was used to estimate yields.

(2) Safety First Calories (SFFTCALS) -- This row requires that total calories produced under unfavorable weather conditions must equal or exceed the minimum annual calories required for the persons in the farm household. All values in the SFFTCALS row are given in kilocalories.

(3) Harvested Grain -- The total harvest of crops may not be exceeded by the sum of human consumption, feed for oxen, and crop sales.

(4) H. H. Consumption -- The ----CONS set of rows requires that at least a minimum of each crop be allocated to consumption to provide variety in the farm family diet. The KCALNEED row forces a minimum level of total calories to be consumed by the family farm. The current requirement is 975 grain

kcal/person/day, with 5 adults and 7 non-adults (valued at 0.5 adults) in the family. The CPST---- set of activities transfers from harvested grain to meet consumption minimums. The CPST---- activities also enter the KCALNEED row. At least one CPST---- activity must be above the minimum to satisfy the total KCALNEED requirement.

(5) Supplement Ox Feed -- The SUPPFEED row requires supply of either produced (feed own grain) or purchased (buy feed grain) grains in amount equalling the oxen "demand" for feed grain. In the TTLOXLBR row, the FEEDSUPP activity determines the demand for feed grain under the assumption that one hour of oxen work, which is accounted in the TTLOXLBR row, requires .5 kilograms of feed grain.

(6) Fodder Ox Feed -- The fodder ox feed requirements are created by the OXENKEEP activity. Fodder supply sources are crop resident (RFIELD--), trees (FEEDTREES), and any land that is fallowed (FALLOWLD). Fodder feed requirements are divided into three seasons: early dry (FODEDRYS row), late dry (FODLDRYS row), and wet (FODDWET row). All crop residue enters the FODEDRYS row where it either meets early dry season requirements or is transferred to the two later season fodder feed rows with some loss in feed value. Grain may be fed (FEEDFRFD) in addition to SUPPFEED to replace part of the fodder requirements.

c. MPSX Format and Variable Naming Scheme

1. MPSX Format

In MPSX format, a programming problem is divided into a commands sections which identifies the objective function to be maximized, the rows section, the columns section, and the right hand sides (rhs) section. All sections of the MPSX-formatted WFPMWA problem are created in a LOTUS 1-2-3 spreadsheet. In MPSX

format, the commands section appears first (see figure 1). Explanation of the command section can be found in the LINDO Manual (Schrage).

The rows section extends over the range A27..B145 in the current LOTUS 1-2-3 worksheet, WFPMWA.WK1. In the section, all rows that will appear in the matrix are identified by name and the type of constraint for the row (E equality, G greater than, L less than) is specified. In the column section, range A145..F4993 in WFPMWA.WK1, the first LOTUS column identifies each activity by an 8-digit alphanumeric name. For each activity, the next LOTUS column identifies the rows which have nonzero values. The third column shows the actual matrix coefficient, a_{ij}, for the particular activity (column) and row. For example, line 2185 in the LOTUS worksheet for WFPMWA is

G21NLAXX GNYLDS20 1043.0

where G21NLAXX is an activity, GNYLDS20 is the row entry for the activity, and 1043.0 is the technical coefficient for the activity and row.

The fourth section in MPSX format is the right-hand-side (RHS) section which extends over the range A4994..F5054 in the current worksheet. All rows with nonzero right-hand-sides are listed along with the current RHS values.

2. Variable Naming Scheme in the Model

(a) Activities

All activities are given eight character alphanumeric names. Activities are divided into the three major categories of production activities: crop harvesting, crop selling, crop consuming, and crop buying activities; ox feed activities, and miscellaneous activities. A given character in a given location serves to identify one attribute of an activity in one of the categories. Together, all eight characters identify the unique attributes of each activity as is shown in Table 1 for production activities.

All production activities are identified according to the system shown in Table 1. The first letter in the name identifies the crop being produced with S representing sorghum, M representing millet, Z representing maize, G representing groundnuts, and V representing vegetables. The second

TABLE 1. Explanation for Production Activity Variable Names.

	Crop Attribute				
Crop	Planting Schedule	Fertilizer	Tied Ridges	Season	Animal Use[1]
S(Sorghum)	1	0 (None)	N (No)	L (Long)	H
M(Millet)	2	1 (Level 1)	T (Yes)	S (Short)	P
Z(Maize	3				A
G(Grdnuts)	4				
V(Vegt.)					

H[1]: No oxen
P[1]: Oxen used only in preplant tillage
A[1]: Oxen Used in tillage, cultivation, and weeding

character in the production activity name shows the planting schedule for the crop. For example, S1 is sorghum grown under planting schedule one and M2 would be a millet crop grown under planting schedule two. The third character indicates the level at which the crop is fertilized. A 0 means the crop is not fertilized and a 1 shows that the crop is fertilized at one level. Level one is the only positive fertilizer rate presently available in the model. The fourth character shows whether tied ridges are used in the crop production activity. If the character is T, then tied ridges are used; if it is N, then tied ridges are not used. The fifth character indicates if the crop is a regular long season crop (L) or a short season crop (S). The sixth character indicates whether oxen are used. An H shows that only human labor, and no animal power, is used in the

production of the crop; a P indicates that oxen are used only in the preplant tillage operation; and an A means that oxen are used in preplant tillage and in cultivation and weeding. The seventh and eighth characters are XX for all crop production activities. Currently the XX only serve to denote activities as crop production activities. If other options such as intercropping are later added to the model, the seventh and eighth characters could be used to indicate their presence. The eight character name for a crop production activity can be illustrated by G21NLAXX, which identifies the activity as groundnuts (G), grown under planting schedule one (2), fertilized at level one (1), where tied ridges are not used (N), where the crop is regular season (L), and where animal traction is used throughout its production (A).

Harvest activities are included in the second section. For the harvest activities the first and second characters denote the crop being harvested (including crop residue as a fodder crop), and the third and fourth characters indicate if the crop is hand harvested (HD), harvested with the help of oxen (OX), or delayed for harvest at a later period (DL). The fifth and sixth character are used to denote the activities as harvesting activities and as such equal HV for all such activities. The seventh and eighth characters indicate the time period in which the harvesting activity is occurring. For example, the variable MLHDHV18 is millet (ML) that is hand harvested (HD) in period 18 (18).

Crop consumption, selling, buying, and oxen feeding activities are also included in the second major category of activities which is measured in kilograms. All human consumption of food activities are denoted by the term CSPT in the first four characters of the variable name; all selling activities have the term SELL as the first four characters; and all crop buying activities have the term BUYS as the first four characters. The last four characters denote the

crop in the consumption, selling, and buying activities (SORG is sorghum, MILL is millet, MAIZ is maize, GRNT is groundnuts, and VEGT is vegetables). FEED as the first four characters in a variable name means the crop is being fed to livestock, (i.e., the oxen).

FEEDSUPP is the activity for feeding any type of grain. FEEDFRFD causes the crop being fed to replace some fodder which comes from crop residue, trees, or fallow land. FDEDTOLD and FDLDTOWT are activities that transfer fodder from the early dry to late dry season and from the late dry season to the wet season.

Miscellaneous activities include temporary hired labor activities, oxen rent and oxen ownership activities, and an erosion yield damage measurement activity. TMPLAB-- provides for the hiring of temporary labor by time period. OXRENT-- provides for renting oxen during the specified time period when needed. The seventh and eighth characters show the period for which the oxen team is rented or the labor is hired. OXINTGER and OXENKEEP are the two oxen ownership activities. OXENKEEP supplies ox labor by period and requires feed and labor inputs for maintenance of the farmer's own oxen.

ERSNDAMG translate soil erosion into costs due to yield damage. ERSNDAMG is measured in tons and has an objective function coefficient which is the monetarized present value of the opportunity cost of future losses in crop production per ton of current erosion.

(b) Constraints

All constraints are listed in the MPSX rows section that appears in the range A27..B145 of the current WFPMWA LOTUS worksheet (WFPMWA.WK1). The rows are divided into two groups for the purpose of describing their names. (A more detailed explanation of constraints can be found in the second section which

describes the structure of the model.) The first group of rows extends over range A28..B98 in the worksheet, and the second group is in range A99..B145.

In the first row "group" OBJTFNCT is the model objective function. LANDSCON is the crop land availability constraint row. ERSNRATE accumulates soil erosion due to production activities as measured in tons. ERSNCONS is a row which can be used to restrict whole farm erosion to a given level.

Also included in the first group of rows are the family and hired labor and ox labor constraints, which are grouped by period and are all measured in terms of hours. Total available labor by period is indicated by the HUMLAB-- set of constraints with the seventh and eighth characters showing the period for which the constraint applies. The RHS value for HUMLAB-- is available family labor by period. For many periods, HUMLAB--can also be augmented by temporary hired labor. Maximum temporary labor hired by period is given by the TEMPLAB-- set of constraints.

OXNLAB-- is the set of constraints on the amount of ox labor hours available in a given period. For any period, the initial value is zero, but OXNLAB-- may be increased by either buying an oxen team or by OXRENT--. The OXRENT-- set of variables is separately constrained in a set of rows (also termed OXRENT..) that reflect limits on the opportunity to hire oxen in peak periods.

The second group of rows contains the --YLDS-- set of rows in the range A99..B117. The --YLDS-- rows are accounting rows in which standing yields from production activities are accumulated. The yield is measured in kilograms. There is a separate row for each crop and each time period when the crop is ripe and ready for harvest. In the --YLDS-- variables, the first and second characters show the crop (MR for maize, SG for sorghum, ML for millet, GN for

groundnuts, and VG for vegetables). The seventh and eighth character indicate the period where the crop is first available for harvest.

Also included in the second group of rows, over range A118..B145, are crop supplies and demand balance rows, minimum consumption constraints, crop residue as fodder harvest rows, and livestock feed requirements constraints. All of these rows are measured in kilograms. Also included is a total ox labor hours transfer row (TTLOXLBR). The KCALNEED row forces total calorie consumed by the farm family to meet or exceed a specified lower bound. The SFFTCALS (Safety First Calories) is a constraint which limits the feasible set of cropping programs to combinations of production activities that meet or exceed the family's minimum calorie requirement under adverse weather conditions. The definition of the minimum calorie requirement and the level of yields under adverse weather conditions as found in the SFFTCALS row may be changed from run to run. The ----SBAL rows, which are measured in kilograms, force sales and human and animal consumption for any given crop to be less than or equal to the production of the crop plus any market purchase of the crop.

The ----CONS set of rows force a minimum variety in diet by requiring at least a minimum amount of each crop to be consumed by the farm family. The SUPPFEED row is used to force supplemental feeding of oxen whenever they are worked. The row, TTLOXLBR, accounts for the hours of ox labor that will be creating requirements for feed. FODEDRYS, FODLDRYS, and FODDWETS are fodder (crop residue plus trees and any fallow (grazed) land) accounting rows between the three fodder feed "seasons".

d. Creating or Changing Coefficients in the MFPMWA Model

The worksheet for creating the MPSX-formatting input file for MWPMWA employs tables that can be used to make relatively quick and easy changes of various

groups of technical coefficients in WFPMWA. Locations of the tables in WFPMWA.wk1 are given in the worksheet directory. Appropriate values in the "MPSX matrix" section of the worksheet equal the values given in the tables. Crop activity yields (the --YLDS-- set of rows), safety first yields in kilocalories (the SFFTCALS row), crop activity erosion rates (the ERSNRATE row), labor coefficients for all sorghum, millet, groundnuts, and maize production activities, forage and feed values, and many objective function coefficient can currently be changed in this manner.

The crop yields table, with a location shown in the worksheet directory, contains yields for specified weather and management conditions. The crop yields table comprises several subtables: base yields, fertilizer yields, yields with animal traction, and yields with both animal traction and fertilizer. In each subtable, yields for all crops are listed by planting schedule, by the presence or lack of tied ridges, and by whether the crop is short season or long season.

The animal traction and fertilizer subtables are functions of values in the basic yields subtable. Fertilized yields are increased by specific percentage over base yields. The percentage rate of increase equals an assumed fertilizer yield increase value divided by maximum potential (no water stress) yields. The percentages rate of increase is then multiplied by the appropriate value from the basic yields table to determine the expected yield with fertilizer. For example, for sorghum the fertilizer rate is 12 kilograms/hectare, the unit yield response is 10 kilograms of grain/kg of fertilizer, and the maximum potential yield is 1250. Therefore, the rate of increase is 12 times 10 divided by 1250 or 9.6 percent. The 9.6 percent is then multiplied by the base crop value to give the yield increase. For schedule 1 basic sorghum (cell H180) the base yield of 996

times 9.6 percent gives an increase of 96 kilograms, and a yield for schedule 1 sorghum with level one fertilizer of 1092 kilograms.

The yield with animal traction is created by a multiplicative factor times the base yield. In the current worksheet, the factor equals 1.05 times the base yield or a 5 percent increase. The increase applies to all crop activities where animal power is used in crop cultivating and weeding, i.e., any crop activity with an A as the sixth character in its variable name. No yield increase (i.e., multiplicative factor of 1.0) is assumed for rotations where oxen are used only in preplant tillage.

To change yields for a particular subset of cropping activities go to the table cell location for that particular activity and make the desired change and then enter F9 (the recalculation command). For example, to change the yield for regular season sorghum planted under schedule 1 in tied ridges, go to the cell location for that group of variables (H156) and enter the new yield. After making the change, hit the F9 (recalculate) button and all appropriate yields in the MPSX matrix will change to the new value. In this case all cropping activities with the nomenclature S1-TL-XX would change to the new value (where the dashes indicate that the change applies regardless of crop fertilizer or animal use status).

The table can be used to make general changes in a category of yields. For example, assume that it was desirable to make a run where long season tied ridges are effectively excluded as farm options. Setting the yields for tied ridges for each long season crop activity to zero (range I156..I165 equal zero) and then hitting the F9 button results in zero yields for all long season cropping activities that use tied ridges.

Changes in "safety first" yields and erosion values are made in a similar manner. Yields for the safety first set of variables are set up in exactly the same manner as for crop yields except yields are given in terms of kilocalories instead of kilograms.

The table for erosion rates appears in the range G342..I358. Erosion rates are given in tons and are listed by planting schedule and by the use or nonuse of tied ridges.

The objective function table contains objective function coefficients for various variables. Within the objective function table, the erosion yield loss objective function coefficient (ERSNDAMG variable) is a function of the value marked total and found in cell H362. Over a 5 year period, the total value is a function of crop sale prices, yield loss per ton of erosion, and normalized crop weights as listed in range I369..J373.

Labor use by crop production activity and time period are listed in G396..K487. For both basic and short season crops, labor activities by activities are listed. To obtain the actual period for which the coefficients apply, Appendix 1 of this manual should be consulted. Labor activities for tied ridges and fertilizer are given separately and, therefore, can be changed independently of other labor coefficients. Short season and animal traction labor coefficients are a function of basic values that can be adjusted independently of the basic coefficient values, by changing the SS (short season) factor and the animal traction multipliers.

Animal forage and feed values from crop production are listed in G489..J503. These values give the amount of forage as a function of crop production, and the conversion of forage into an "animal support" (forage units) value. Forage and feed values are a function of yield levels and a basic zero crop yield value.

The amount of forage obtained per unit of yield, the basic zero yield value, and the animal unit forage conversion factor, can all be changed in this portion of the spreadsheet.

A few extra tips are in order. Be careful in changing the multiplicative factors in the two animal traction tables for either the yields or safety first yields. Since the animal traction yield factor is multiplicative, setting it at zero will cause all cropping activities that use animal traction in weeding and cultivating to have zero yields. Use a factor of 1.0 to reflect a zero yield increase. Finally, be careful to save a version of the model with all values at their original level.

e. Creating a Print (.prn) file to run on LINDO

After all desired changes have been made, a LOTUS 123 print file (**.prn) can be created to run immediately on an IBM-PC version of LINDO. The PC must have at least 512 K of memory. Some slight modifications to the commands found in the worksheet are probably necessary to use the print file in mainframe versions of LINDO or MSPX.

Follow the directions given in the LOTUS manual for creating the **.prn file. The range to use in creating the .prn file from the current WFPMWA.WK1 is found in the worksheet directory. The directions given in the manual are not difficult to follow; however, it is important to always make sure that the left margin in the .prn file equals zero and that the UNFORMAT command is invoked. If UNFORMAT is <u>not</u> used, page breaks will appear in the .prn file and if the left margin is <u>not</u> set at zero, the first column will be a set of blanks. In either case the model will not execute.

A final word of caution is also in order. Making changes in the MSPX matrix section of the worksheet is not a good idea until the user has gained a great deal of familiarity with the model.

IV. DOCUMENTATION FOR WFPMWA

This section documents data sources for coefficients in the Whole Farm Planning Model for West Africa (WFPMWA). Initially, the model's subdivision of the cropping season by time period is explained. Second, the paper presents the documentation for model coefficients as divided into five sections: 1) the coefficients for long season and short season crop yields, and safety-first crop yields, 2) the coefficients for consumption and sale of farm crops and purchase of feed grains, 3) labor coefficients, 4) erosion and erosion yield damage coefficients, and 5) coefficients related to oxen ownership or renting oxen.

Time Periods in WFPMWA

Based on Day's unpublished data for his GAMS model, the cropping season is currently divided into 17 time periods of 15-16 days each and a single 105 day period. Each cropping activity is divided into stages that occur at fixed periods of time before or after planting. Each farming operation occurs during a certain period of time and requires a certain amount of human labor for all activities and oxen labor for many activities. In the model, each period of time is assigned a number as shown in Table 1. Numbers are used in variable names and row names to denote the time period in which model activities occur. For example, HUMLAB08 relates to the supply of and demand for labor in period 08 (April 16 through April 30) and MZHDHV16 is maize harvesting in period 16 (August 16 through August 30).

Model Yields

Basic model yields that are shown in Table 2 are derived from a water-yield model constructed by Day (Butcher and Day, 1987) using precipitation data for a "median" year at Kita, Mali. (A detailed explanation of the water-yield

TABLE 1. Time Period Numbering Scheme in WFPMWA

Time Period	Number
January 1 - April 15	07
April 16 - April 30	08
May 1 - May 15	09
May 16 - May 30	10
June 1 - June 15	11
June 16 - June 30	12
July 1 - July 15	13
July 16 - July 30	14
August 1 - August 15	15
August 16 - August 30	16
September 1 - September 15	17
September 16 - September 30	18
October 1 - October 15	19
October 16 - October 30	20
November 1 - November 15	21
November 16 - November 30	22
December 1 - December 15	23
December 16 - December 30	24

Source: Day, John. Unpublished Data for GAMS Malian Whole Farm Model. Washington, D.C. 1987.

TABLE 2. Basic, Tied Ridges, and Maximum Yields, for Long and Short Season Sorghum, Millet, Maize, and Groundnuts

	Long Season			Short Season		
	Basic	Tied Ridges	Maximum	Basic	Tied Ridges	Maximum
	(kg)					
Sorghum			1250			1130
schedule 1	996	1212		719	911	
schedule 2	1006	1172		884	1130	
schedule 3	954	1000		1008	1130	
Millet			1000			820
schedule 1	791	938		554	663	
schedule 2	801	915		640	779	
schedule 3	777	825		718	820	
Maize			1200			1080
schedule 2	707	977		401	674	
schedule 3	723	941		710	1055	
Grdnuts			1400			1290
schedule 2	921	0		625	0	
schedule 3	950	0		847	0	
schedule 4	878	0		1042	0	

NOTES: A rainfall infiltration rate of 40 percent is assumed for basic yields and an infiltration rate of 60 percent is assumed for yields with tied ridges.

Maximum yields occur under optimal (no water stress) growing conditions.

model can be found in Appendix 3.) Crop yield response to moisture stress during crop growth stages is estimated using relationships developed by the Food and Agricultural Organization of the United Nations (Doorenbos and Pruett, 1975; Doorenbos and Kassam, 1979). The water-yield model can be used to estimate crop yields under a wide variety of weather and management scenarios.

Safety-first crop yields are also estimated with Day's yield-water model. Safety-first yields are expressed in terms of kilocalories (a kilocalorie equals 1000 calories). These yields incorporate risk considerations by reflecting the farmer's concern that total calories produced under unfavorable weather conditions must equal or exceed the minimum calorie intake that is required for the farm family. In the current model, unfavorable yields are derived from Day's water-yield model under the assumption of weather conditions equivalent to those of the least productive year, which is expected in a ten year period, as based on the 43 years for which weather data are available. The calorie requirements in the basic model are based on a 12-member household with average calorie requirements, as satisfied by grains, equal to 975 kilocalories per person per year.

Farmers can use tied ridges, fertilizer, and animal traction throughout the cropping season to augment both expected yields and safety-first yields. As noted in Table 2, tied ridges are assumed to increase rainfall infiltration rates from 40 to 60 percent; increased infiltration results in greater available moisture and higher yields which are estimated in Day's water-yield model as further explained in Appendix 3.

Fertilizing increases crop yields as based on the formula provided by Day

$$YLD_{fl} = YLD_{basic} \; (1 + (YLD_{basic}/YLD_{max}) * \Delta \; YLD_{fert})$$

where YLD_{fl} is the fertilized crop's yield, YLD_{basic} is base yield obtained from the yield-water model, YLD_{max} is maximum (no water stress) yield, and ΔYLD_{fert} represents the maximum (no water stress) increase in yield per unit of fertilizer. This formula assumes that the yield increase from fertilizer is proportionately less when the crop is suffering from moisture stress. Fertilizer application rates and maximum yield responses currently assumed in the model are given in Table 3.

Fertilizer prices are taken from Day (1987). In the current model, the cost of fertilizer is a negative objective function value for any fertilized crop activity. Cost per hectare is the fertilizer application rate (in kilograms) multiplied by the per kilogram price of fertilizer.

According to the literature, the introduction of animal traction has resulted in changes in yields that range from no increase up to 50 percent yield increases (Jaeger, 1986). Based on Day's yield increase for sorghum and millet with animal traction, an increase in yields of 5 percent is assumed whenever oxen are used in both preplant tillage and in crop weeding and cultivating. The 5 percent increase applies equally to all crops. In the current model, there is no yield increase when oxen are used only in preplant tillage.

Food Consumption, Selling and Purchase

Food consumption by the farm family, selling surplus output, and the purchase of feed for oxen are also activities in WFPMWA.

Total family food consumption must meet recommended daily calorie intake allowances (USDA, 1987). The farm model is comprised of 5 adults and 7 non-adults (Day; Fleming). Daily minimum calorie requirements are 3 kilocalories for three members, 2.5 kilocalories for six members, and 2.2 kilocalories for three members. The average daily caloric requirement per family member (2.55

TABLE 3. Fertilizer Rates, Costs, and Maximum Fertilizer Yield Response

	Maximum Rate		Maximum Yield Response (per kg)
	Nitrogen	Phosphate	
	-------(kg)-------		
Sorghum	12.0	4.0	10.0
Millet	18.0	6.0	10.0
Maize	12.0	4.0	10.0
Groundnuts	----	10.0	11.0

NOTES: Maximum yield response is a function of nitrogen rates for sorghum, millet, and maize, and of phosphate rates for groundnuts.

Nitrogen costs 200 MF per kilogram; phosphate costs 235 MF per kilogram. Both nitrogen and phosphate are applied at their maximum rates.

kilocalories) in the model is 1160 calories higher than reported daily per capita caloric intake for northern Nigeria (Banta and Bbuyemusoke, 1985).

Caloric intake requirements of the farm family are met by the consumption of grains and groundnuts. Kilocalories per kilogram of crop yield are 3.32 for sorghum, 3.27 for millet, 3.48 for maize, and 5.46 for groundnuts (USDA, 1963). Vegetables do not contribute towards calorie intake requirements.

A minimum variety in the family diet is also imposed. Based on per capita values given by Day and originally reported by Fleming, a minimum of 480 kg each of sorghum, millet, and maize, and 120 kg each of groundnuts and vegetables, must be produced and supplied for family consumption. Additional food required to meet total caloric requirement may be supplied by grains and groundnuts. Amounts produced in excess of minimum calorie and diet diversity requirements may be sold.

Crop selling prices are taken from Day and Fleming. Crop prices are a weighted average of open market prices and less lucrative state market prices based on Day's assumption that 90 percent of all marketable output is sold on the open market while the remaining 10 percent is sold on the state market. Open market price for any grain is assumed to be 100 MF per kilogram and a state market purchase price of 40 MF per kilogram is assumed. Therefore, the price for any marketed grain is 94 MF (.90 times 100 plus .10 times 40).

Supplemental feed grain must be supplied to oxen at a rate of 6 kg per ox team per day of work. Feed grain can also be used to substitute for fodder, if necessary, to meet minimum maintenance feed requirements. Feed grain may be supplied out of salable surplus above household consumption requirements or it may be purchased. Feed grain purchase prices are those observed by one of the authors in Burkina Faso.

Labor Coefficients

With the exception of harvest activities, all labor coefficients are provided by Day. Labor coefficients by cropping periods for pre-season land clearing, preplant tillage, crop planting, and crop weeding and cultivation are given in Table 4. With the exception of land clearing, the use of oxen in any operation is assumed to reduce labor demands. For example, animal (oxen) traction is assumed to cause a 25 percent decline in the human labor required for preplant tillage.

Tied ridges cause a total increase in labor requirements of 100 hours (50 hours in both the second and third weeding periods). Although the amount of labor required for tieing ridges can vary greatly, the increase of 100 hours for the manual tieing of ridges is the same as reported by Sanders and Roth (1985). The use of animal traction is assumed to reduce the labor required for tieing ridges by 25 percent.

The literature gives various figures for increases in labor that result from fertilizing. For example, Sanders and Roth state that fertilizing causes a total increase in labor of 75 hours; Jaeger says that fertilizing only requires a labor increase of 5 hours. In WFPMWA, fertilizing is assumed to increase labor requirements by a total of 6 hours (3 hours in the planting period and 3 hours in the first weeding period).

The timing of labor operations varies by crop and by planting schedule (Appendix 2). Crop planting dates are varied because of variation in the onset of the rainy season and because of the need to reduce labor requirements at crucial periods when such requirements may exceed labor supply. Farmers generally do not begin tilling and planting until the first wet season rains occur at the beginning of the rainy season. A different planting date for the

TABLE 4. Labor Use Coefficients for Selected Crops Where Tied Ridges, Fertilizer, and Animal Traction Are Not Used

Period	Activity	Sorghum[1] Schedule 1	Activity	Maize[2] Schedule 2	Ground-nuts[3] Schedule 2	Activity	Vegetables[4] Schedule 3
HUMLAB07	Clear Land	18	Clear Land	15	15	Clear Land	15.0
HUMLAB09	Tillage	40					
HUMLAB10	Plant	85	Tillage	50	110		
HUMLAB11	Cultivate/Weed	20	Plant	88	168	Tillage	153.0
HUMLAB12	Cultivate/Weed	37	Cultivate/Weed	58	30	Plant	153.0
HUMLAB13	Cultivate/Weed	53	Cultivate/Weed	116	56	Cultivate/Weed	110.0
HUMLAB14	Cultivate/Weed	70	Cultivate/Weed	116	83	Cultivate/Weed	162.0
HUMLAB15	Cultivate/Weed	70	Cultivate/Weed	58	112	Cultivate/Weed	109.0
HUMLAB16	Cultivate/Weed	53	Cultivate/Weed		109	Cultivate/Weed	83.0
HUMLAB17	Cultivate/Weed	37	Cultivate/Weed		83	Cultivate/Weed	83.0
HUMLAB18	Cultivate/Weed	20	Cultivate/Weed		56		
HUMLAB19		3	Cultivate/Weed		30		
HUMLAB20		3					
HUMLAB21		3					
Total Hours		512		868	501		852

[1]S10NLHXX is the variable name for schedule 1, regular season sorghum, without tied ridges, fertilizer, and animal traction. All values for sorghum also apply to millet.

[2]Z20NLHXX is the variable name for schedule 2, regular season maize, without tied ridges and animal traction. (Fertilizer is not an option for long season maize.)

[3]G20NLHXX is the variable name for schedule 2, regular season groundnuts, without fertilizer and animal traction. (Tied ridges are not an option for groundnuts.)

[4]V30NLHXX is the variable name for schedule 3, regular season vegetables, without animal traction. (Neither tied ridges nor fertilizer are not options for vegetables.)

Tied ridgea causes a 50 hour increase in labor in both the second and third weeding periods.

Fertilizing causes a 3 hour increase in labor in both the planting and 3rd weeding period.

Any use of animal traction causes a 20 percent increase in land clearing period labor.

Any use of animal traction causes a 25 percent reduction in tillage period labor.

Using animal traction for planting causes a 48 percent reduction in planting period labor.

Using animal traction for cultivating and weeding causes a 34 percent reduction in labor for all cultivate and weed periods.

Using animal traction for cultivating and weeding causes a 20 percent reduction in tied ridges labor requirements.

same crop shifts the timing of crop operations and labor demand, but the same amount of labor is still required for each farming operation.

Varieties with shorter growing seasons are also farmer options in the WFPMWA. As shown in Table 5, short season varieties take less time than regular varieties in forming vegetation, in flowering, and in setting fruit (yield formation). Because of the shorter growing season, short season varieties are assumed to have reduced crop weeding and cultivating labor requirements.

Labor coefficients were formed for short season activities by linking farmer activities (e.g., cultivation and weeding) to crop growth stages (e.g., flowering) for both regular long season and short season varieties. The crop growth stages that are reduced in length in short season varieties provided a guide for reducing total labor demand for the short season crop (Table 5). For example, a comparison of short season sorghum takes one less two-week period than long season sorghum for the formation of vegetation, for flowering, and for forming yield. For long season schedule 1 sorghum, vegetation occurs in periods 11 and 12, flowering happens in periods 13 and 14, and yield formation occurs in periods 15 through 17. Therefore, labor demands in period 11 (for vegetation), period 13 (for flowering), and period 17 (for yield formation) were deleted from the long season variety to form the labor schedule for short season sorghum. Accordingly, the short season crop required 112 less hours of total labor (a reduction of 22 percent). Of course, the short season hybrid is also available for harvest 6 weeks earlier than the regular varieties.

TABLE 5. Comparison of Long and Short Season Schedule 1 Sorghum Labor Use by Crop Activities and Crop Growth Stage Periods

Short Season[1]				Long Season[2]			
Period	Labor (hrs)	Land Use	Crop Growth Stage	Period[3]	Labor (hrs)	Land Use	Crop Growth Stage
HUMLAB07	18	Clear Land		HUMLAB07	18	Clear Land	
HUMLAB09	40	Till		HUMLAB09	40	Till	
HUMLAB10	85	Plant	Establish	HUMLAB10	85	Plant	Establish
HUMLAB11	37	Cult./Weed	Vegetation	HUMLAB11	20	Cult./Weed	Vegetation
HUMLAB12	70	Cult./Weed	Flower	HUMLAB12	37	Cult./Weed	Vegetation
HUMLAB13	70	Cult./Weed	Yield Form	HUMLAB13	53	Cult./Weed	Flower
HUMLAB14	53	Cult./Weed	Yield Form	HUMLAB14	70	Cult./Weed	Flower
HUMLAB15	20	Cult./Weed	Ripen	HUMLAB15	70	Cult./Weed	Yield Form
HUMLAB16	3			HUMLAB16	53	Cult./Weed	Yield Form
HUMLAB17	3			HUMLAB17	37	Cult Weed	Yield Form
HUMLAB18	3			HUMLAB18	20	Cult./Weed	Ripen
				HUMLAB19	3		
				HUMLAB20	3		
				HUMLAB21	3		
Total	403				512		

[1]S10NSHXX is the variable name for schedule 1, short season sorghum, without tied ridges, animal traction, and fertilizer. All values for sorghum also apply to millet.

[2]S10NLSHXX is the variable name for schedule 1, regular season sorghum without tied ridges, animal traction, and fertilizer. All values for sorghum also apply to millet.

[3]In going from long season to short season schedule 1 sorghum, long season labor requirements for periods 11, 13, and 17 are deleted.

Labor coefficients for crop harvesting activities are taken from Jaeger (1986) with the exception of the labor coefficient for vegetable harvest. All grains are assumed to take 0.10 hours per kilogram of final product for harvesting and threshing of the crop while peanut harvest requires 0.35 hours per kilogram of output. Vegetable harvesting is assumed to take 0.20 hours per kilogram of output. Using a team of oxen to help with threshing and with hauling grain and fodder from the field is assumed to reduce harvest labor demands by 90 percent.

Human labor can be supplied by the family or by hired labor. All labor supply values are taken from Day and from Fleming. The family labor pool provides 5 adult equivalent workers. Each adult equivalent worker is assumed to work 13 days in each 15 day labor period. Total hours of available family labor per period, the right-hand sides for the HUMLAB -- set of rows in WFPMWA, is the product of the number of hours in the working day. Total hours of family labor can vary by periods because the number of hours worked in a day is not constant across periods. Work days for each adult equivalent worker by period are as follows: a 4-hour work day for period 07 (January 1 through April 15), 6-hour for periods 09 and 10 (April 16 through April 30), 7.5 hour for periods 11 and 12 (the month of June), 8.5 hours for periods 13 through 16 (July through August), and a 7-hour work day in periods 17 through 24 (September 1 through December 30). Calculations for labor supplied by temporary workers operate under the same assumptions as family labor except that a maximum of 20 temporary workers can be hired for any time period and hired labor is not free. Per hour cost of hired labor, as taken from Day and from Fleming, can also vary between periods.

Oxen labor is supplied by an owned or rented team of oxen. Assuming that oxen are worked for 4 hours each day and allowed two rest days during each 15 day work period a team of oxen can provide a maximum of 52 hours of work per period.

Erosion and Erosion Yield Damage Coefficients

Estimating yield damages from soil erosion requires determining what type of soils comprise a typical area farm, arriving at a reasonable soil loss estimate for the region, and assessing the functional relationship between yield damage and erosion.

The composition of arable soils was estimated from soil surveys found in the TAMS Report on Mali Land and Water Resources (no date). In the report, an aerial photograph of the Kita region showed its division by soil group. Using the line transect method that is described in Pielou, the amount and composition of arable land in the region was ascertained. Soils were determined to be arable based on their description and recommended uses as given in the TAMS Report.

Virtually all arable land in the Kita region consists of soils which fall into the Alfisol, Ultisol, and Inceptisol soil order categories of the USDA Soil Taxonomy System (Table 6). These soils generally have inherently poor to fair capacity for cropping, are susceptible to erosion, and experience sharp declines in soil productivity if soil erosion occurs. Many tropical Alfisols easily form surface crusts, are structurally unstable, have quickly declining infiltration rates after cultivation, consist of only 1-2 percent organic matter with rapid turnover, and often have argillic and gravel subsoils which result in shallow effective rooting depth (Stocking and Peake 1986). Further, many of the soils in the Kita region also overlay various forms of laterite which can inhibit rooting depth.

TABLE 6. Description and Overall Composition of Arable Soils for the Kita Region of Mali, Africa

Soil Type	Total Land	Total Arable Land	Slope[1]	Slope Description	Underlying Laterite or Rock
	--------(Percent)--------				
Aridic Haplustalfs	4.6	8.5	3	Flat - Gentle Sloping	None
Plinthic Haplustalfs	6.6	12.3	0	Flat	Plinthite
Typic Cuirustalfs	11.9	22.2	2.8	Almost Flat - Gentle Sloping	Laterite Curiasse
Typic Cuirustalfs	10.6	19.9	7	Almost Flat - Moderately Steep	Laterite Curiasse
Oxic Haplustults	10.8	20.2	4	Gentle Sloping	Laterite (at some Depth)
Oxic Ustropepts	2.8	5.3	1	Almost Flat -	Some Plinthite
Lithic Ustropepts	4.5	8.4	13	Sloping - Steep	Sandstone
Mollisols	1.7	3.2	2	Flat - Very Gentle Sloping	None
Total	53.4	100			
Average Slope[2]			4.3		

Source: TAMS Ingenieurs, Architectes et Planificateurs. Mali Land and Water Resources. for Mali Government/USAID Grant Agreement 688-0205. TAMS Ingenieurs, Architectes et Planificateurs. N.Y. No Date.

[1]Slope values are point estimates taken from the range of values given for the slope description of each soil type.

[2]Average slope is the sum, over all arable soils, of the estimated slope value for each soil type multiplied by its percentage of arable land.

There are several soil erosion estimates for Western Africa but none that would be as widely accepted as, for example, the Universal Soil Loss Equation (USLE) that is used in temperate areas of the U.S. Unfortunately, there are no soil loss measures for the Kita region of Mali. Based on soil plot data from Lal (1984) made in Idaban, Nigeria, a maximum erosion rate of 60 tm/ha is assumed for a bare fallow field of variable length and 5 percent slope. (A 5 percent slope was chosen because it was closest to the weighted average slope for the Kita region that is given in Table 6). The erosion rate is a very rough approximation and could easily over-or underestimate actual maximum potential erosion.

Physical erosion control structures and crop cover will reduce erosion to less than the maximum value. The Universal Soil Loss Equation (USLE) can be used to estimate the effect of such practices by multiplying maximum potential erosion by physical structure (P) and crop cover (C) factors. According to Roose (1977), crop cover factors in Western Africa range from 0.4 to 0.9 for millet, maize and sorghum and from 0.4 to 0.8 for groundnuts. Actual factors used in the model and shown in Table 7 vary within these ranges according to seeding schedule. Tied ridges, the only structural erosion control practice used in the model, is assumed to reduce erosion by 80 percent (P = .2).

Declines in crop yields as a function of erosion are taken from equations based on research by Lal for maize and cowpeas (Lal, 1987; Stocking and Peake). Lal's yield loss equation for maize on a 5 percent slope is

$$Y = 6.70 * e^{-0.003X}$$

and for cowpeas on a 5 percent slope

$$Y = 0.64 * e^{-0.006X}$$

TABLE 7. C Factors and Erosion Rates for the WFPMWA

Crops/Schedules	C Factor	Erosion Rates No Tied Ridges	Erosion Rates Tied Ridges
		------(MT/HA)------	
Millet/Sorghum 1 Groundnuts 2	.5	30	6
Millet/Sorghum/ Maize 2 Groundnuts/ Vegetables 3	.6	36	7.2
Millet/Sorghum/ Maize 3 Groundnuts/ Vegetables 4	.7	42	8.4

Sources: Roose, E.J. Use of the Universal Soil Loss Equation to Predict Erosion in West Africa. p 60-74 in Soil Erosion: Prediction and Control. ed Foster, G. Soil Conservation Society of America, Ankemy, IA. 1977.

Lal, Rattan. Effects of Slope Length on Erosion of Some Alfisols in Western Africa. Goederma 33 (1984) 181-189.

NOTES: Maximum potential erosion (C=1P=1) is assumed to be 60 mt/ha.

Tied Ridges are assumed to reduce erosion by 80 percent (p=.2).

where Y is yield measured in metric tons, X is cumulative erosion measured in tons per hectare, and e is a constant equal to 2·7183. As shown in Table 8, Lal's two equations were solved to find yield loss per ton of soil loss. Declines in yields for maize, millet, and sorghum on semi-arid dry lands in the Kita region were assumed to be 20 percent of the decline in yields found on Lal's much higher yielding maize plots. Groundnut yield declines attributable to erosion were assumed to be roughly equal to Lal's estimate of cowpeas yield loss from erosion. Like the estimates of erosion used in the model, yield declines as a function of erosion are gross approximations which may over-or underestimate actual yield/topsoil loss relationships.

Coefficients Related to Oxen Ownership and Oxen Rentals

The ownership or the renting of oxen are also model options. Important oxen coefficients are oxen ownership costs, oxen rental costs, and oxen fodder and concentrated feed requirements.

Oxen require fodder as feed throughout the year, and require feed grains whenever they are worked. Annual fodder feed requirements are divided into three seasons: the early dry season, from October 16 through January 31, (a total of 108 days); the late dry season, From February 1 through May 15, (a total of 104 days); and the wet season, from May 16 through October 15, (a total of 153 days). Crop residue harvested as fodder at the start of the early dry season is assumed to lose 50 percent of its feed value if fed in the late dry season while a 75 percent loss in original feed value is assumed for fodder feed in the later wet season.

According to Peace Corps Manual M-12, entitled "Animal Traction" (1981), team of 300 kilogram oxen requires 5.2 daily forage units for maintenance. For the early dry and late dry seasons, animal maintenance requirements are completely met by crop residue and tree fodder, and the grazing of fallow land.

TABLE 8. Solution to Lal's Topsoil/Yield Equations for Maize and Cowpea Adjusted for Conditions in the Kita Region of Mali.

	Maize[1]			Cowpeas[2]		
Erosion (ts/ha)	Yield (mts)	Yield Loss (mts)	Yield Loss[3] (kg/ton)	Yield (mts)	Yield Loss (mts)	Yield Loss[4] (kg/ton)
10	6.50	0.20	3.97	0.60	0.04	3.72
20	6.31	0.39	3.90	0.57	0.07	3.51
30	6.12	0.58	3.85	0.53	0.11	3.30
40	5.94	0.76	3.79	0.50	0.14	3.12
50	5.77	0.93	3.73	0.47	0.17	2.93
60	5.60	1.10	3.68	0.45	0.19	2.76
70	5.43	1.27		0.42	0.22	
80	5.27	1.43		0.40	0.24	
90	5.11	1.59		0.37	0.27	
100	4.96	1.74		0.35	0.29	

Source: Lal, Rattan. "Effects of Soil Erosion on Crop Productivity". CRC Critical Reviews in Plant Science. 5(4) 303-367 1987.

[1]Values for maize are applied to sorghum, millet, and maize in WFPMWA.

[2]Values for cowpeas are applied to groundnuts in WFPMWA.

[3]In WFPMWA, Yield declines per ton of soil loss for millet, sorghum, and maize are assumed to be 20 percent of maize yield losses as given by Lal's equation.

[4]In WFPMWA, Yield declines per ton of soil loss for groundnuts are assumed to be roughly equal to cowpea yield losses as given by Lal's equation.

TABLE 9. The Supply of Oxen Forage Requirements

Forage	Percent Dry Matter	Percent Digestible Protein	Percent Phospho-rous	Percent Calcium	Forage Units	Forage Units Equivalent[1]
		------(100 % dry matter basis)-----				(per kg)
Millet[2] (dry leaves and stalks)	85.0	1.9	0.14	0.55	0.36	0.3060
Corn (dry leaves, husks, and stalks)	93.6	0.8	-----	-----	0.53	0.4961
Peanut Hay (as fed)	92.1	6.3	0.13	1.19	0.40	0.3684
Wet Fallow[3]	25.6	7.5	0.10	0.87	0.72	0.1843
Dry Fallow[4]	30.8	3.2	0.18	0.30	0.48	0.1478

Source: Watson, Peter R.. Appropriate Technologies for Development: Animal Traction Peace Corps Information & Exchange Manual M-12. eds. Richard Davis and Marilyn Chakroff. TransCentury Corporation, Washington, D.C., August 1981.

[1]Forage unit equivalents equal forage units multiplied by percent dry matter.

[2]Values for millet are also assumed to also hold for sorghum.

[3]Wet fallow is assumed to be a mixture of pasture grasses and legumes.

[4]Dry fallow is average quality drier (standing hay) pasture.

For the wet (working) season, fodder is required for maintenance and concentrated feed is required as a supplement when the oxen are worked.

Crop residue and fallow land are converted into forage units through the use of values found in the Peace Corps Manual, which are shown in Table 9. Forage unit equivalents per kilogram of crop residue are found by multiplying the crop's percentage dry matter by its forage unit equivalent (which assumes 100 percent dry matter). The result is the actual forage unit per kilogram of crop residue,which is used to convert total crop residue into equivalent forage units. Trees are also assumed to provide some fodder under the assumption of 25 mature trees/ha with each tree providing one forage unit as observed by one of the authors.

Oxen worked in the wet season require concentrated feed. Feed requirements are met by feeding either on-farm produced or market purchased grains. Using values found in Peace Corps Manual M-12 and assuming a 4-hour work day of primarily medium (cultivating and weeding) and some heavy (plowing) work, an hour of work is assumed to require 0.75 kg of concentrated feed per ox. For a 300 kilogram ox, medium work requires 2.6 kilograms of grain per day while heavy work requires 3.9 kilograms of feed grains. Assuming a 4-hour work day and daily concentrated feed needs of 3.0 kilograms results in the 0.75 per hour requirement. Besides meeting concentrated feed requirements, each kilogram of feed grain reduces the requirements for fodder as feed by one forage unit.

The cost of oxen ownership includes the amortized costs of owning a team of oxen and oxen-drawn implements, implement repair cost, and annual veterinary and incidental oxen care costs. With the exception of the salvage value for a team of oxen, all oxen cost data is drawn from unpublished budget data for the TAMS Report on Mali Land and Water Resources (1980).

Figure 1. Ownership and Maintenance Costs for Oxen and Oxen-Drawn Equipment

Ownership Cost

	Purchase Price	Salvage Value	Useful Life	Annual Depreciation Plus Interest
	------(MF)-------			-------(MF)--------
Oxen	200000	200000	5	24000
Equipment[1]:				
Multicultivator	94310	------	8	18945
Seeder	61610	------	8	12402
Oxen Cart	135470	------	10	23978
Total Annual Oxen and Equipment Fixed Cost				79325

Maintenance Cost	Annual Cost
	---(MF)----
Equipment Repair and Maintenance	4680
Oxen Care (Veterinary, Harnesses, etc.)	225

Total Oxen and Equipment Maintenance Cost	4905
Total Annual Cost (Sum of all Fixed and Maintenance Cost)	84230

Source: TAMS Ingenieurs, Architectes et Planificateurs. Unpublished Crop Budgets for Mali Land and Water Resources. for Mali Government/USAID Grant Agreement 688-0205. TAMS Ingenieurs, Architectes et Planificateurs. N.Y. No Date.

Notes: [1]Assuming a 12 % interest rate,--as given in the TAMS Report--a capital recovery factor of .2013 is used for the multicultivator and the seeder, and a factor of .1770 is used for the ox cart.

All purchases prices, years of useful life, equipment and oxen maintenance cost, and equipment salvage values are taken from the TAMS Report. Estimated salvage value for oxen are based on results from the TAMS report; Jaeger; and Roth, Abbott, Sanders, and McKenzie.

As shown in Figure 1, the oxen-drawn equipment consists of a multicultivator, a seeder, and an oxen cart. Capital recovery factors consistent with an interest rate of 12 percent -- as given in the TAMS report data -- and useful life estimates were used to calculate annual fixed ownership cost of the equipment and for a team of oxen.

The salvage value for the oxen was set so that their value remained constant over the five-year period for which they are worked (Figure 2). The constant valuation of oxen over time was a compromise between the unpublished TAMS data where oxen depreciated by 60,000 MF and values given in both Jaeger; and Roth, Sanders, Abbott, and McKenzie (1986) for Burkina Faso where plow oxen appreciated in value over time. The increased salvage value is also justified by assuming good animal nutrition which would result in a higher quality oxen carcass and higher oxen salvage value (TAMS no date).

All equipment repair cost and the cost of oxen care, as reported in Figure 1, were taken from unpublished TAMS report data. The value of grains fed to the oxen is not included in the cost estimates because feeding oxen is an activity which is endogenous to the model. Repair and maintenance costs are assumed to not vary with use and are therefore added to the fixed ownership costs in forming an objective function value of 84,230 MF for the integer oxen ownership variable in WFPMWA.

Also included in the model is an oxen renting activity. The charge for rented oxen is set at rate of 700 Malian Francs per hour, which equals Jaeger's value for a village in Burkina Faso (1983).

V. REFERENCES AND APPENDIXES

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Appendix 1. A simplified description of the linear-programming model empl in this analysis may be written as follows:

(1) $$\text{MAX } A = \sum_i P_i \sum_i Y_i X_i - \sum_i (D_i + HC_i) + \sum_i P_i \sum_i HC_i$$

$$- \sum_i PF_f \sum_i F_{fi} X_i + \sum_i PS_i S_i X_i + \sum_t PL_t \sum_i L_{ti} X_i$$

subject to:

(2) $\sum_i L_{ti} \geq LA_t$

(3) $\sum_i X_i \geq HA$

(4) $\sum_i Y_i X_i - D_i \geq HC_i$

(5) $\sum_i B_i X_i \geq \sum_i X_i \geq HC_i$

(6) $X_i \geq 0$

where:

i = crop type

t = time period

P_i = price of the ith crop

Y_i = yield per hectare of ith crop

X_i = hectares of ith crop

D_i = deductions (kg) of ith crop for seed, gifts, and crop loss

HC_i = home consumption of ith crop

PF_f = price of fth fertilizer

F_{fi} = f^{th} fertilizer use per hectare of ith crop

PS_i = price of seed for the ith crop

S_i = seed use per hectare of the ith crop

PL = price of labor

L_{ti} = labor hours in t^{th} time period per hectare of ith crop

LA_t = labor hours available in the time period t

HA = hectares of land available for crop production

B_i = safe minimum assured yield of ith crop

Appendix 2. Changes in the Timing of Cropping Activities Between the Different Long Season Sorghum Planting Schedules

ACTIVITY	Schedule 1 PERIODS	Schedule 2 PERIODS	Schedule 3 PERIODS
Clear Land	HUMLAB07	HUMLAB07	HUMLAB07
Tillage	HUMLAB09	HUMLAB10	HUMLAB11
Plant	HUMLAB10	HUMLAB11	HUMLAB12
Cultivate/Weed	HUMLAB11	HUMLAB12	HUMLAB13
Cultivate/Weed	HUMLAB12	HUMLAB13	HUMLAB14
Cultivate/Weed	HUMLAB13	HUMLAB14	HUMLAB15
Cultivate/Weed	HUMLAB14	HUMLAB15	HUMLAB16
Cultivate/Weed	HUMLAB15	HUMLAB16	HUMLAB17
Cultivate/Weed	HUMLAB16	HUMLAB17	HUMLAB18
Cultivate/Weed	HUMLAB17	HUMLAB18	HUMLAB19
Cultivate/Weed	HUMLAB18	HUMLAB19	HUMLAB20
	HUMLAB19	HUMLAB20	HUMLAB21
	HUMLAB20	HUMLAB21	
	HUMLAB21		

Appendix 3. Water-Yield Relationships and Rainfall Infiltration

Crop yields in dryland farming areas of Mali and throughout West Africa are very strongly affected by the amount and timing of rainfall. A water-yield model was designed to estimate yield under various weather conditions. The model is used not only to estimate the distribution of crop yields over a range of different weather conditions but also to estimate the change in average yield in distribution of yield that would be realized with changes in planting date, tillage practices, soil moisture management practices and measures, and crop growing season.

Crop yield response to moisture stress during growth stages was estimated using relationships developed by the Food and Agricultural Organization of the United Nations (Doorenbos and Pruett, 1975; Doorenbos and Kassam, 1979). The basic relationship between crop yield and moisture stress is assumed in the FAO methodology as:

$$(1) \quad \sum_{t=1} 1 - \frac{Y_a}{Y_m} = k_{yt} \quad 1 - \frac{ET_{at}}{ET_{mt}} \qquad (t = 1, \ldots, 24)$$

where:

Y_a = actual harvested yield;

Y_m = maximum potential yield;

ET_{at} = actual moisture available for crop evaporation in time period t;

ET_{mt} = maximum potential crop evaporation in time period t;

k_{yt} = response factor relating decline in Y_a to the moisture deficit in time period t; and

t = half-month time periods.

Calculation of the yield decline due to moisture stress is carried out separately in each time period during the growing season. The moisture stress response factor, k_{yt}, varies from period to period as the plant exhibits different degrees of impact on ultimate yield due to water stress occurring at different stages in the growth of the plant. For example, maize is very sensitive to moisture stress during the flowering period. Thus, the k_y factor for maize during that stage of its growth is relatively high. Millet and sorghum also are sensitive to moisture stress at the flowering stage of growth, although not as sensitive as is corn. During time periods before the planting of the crop and after all growth is completed, the k_{yt} values are zero.

The FAO indicates that the relationship between moisture stress and yield production is approximately linear. That is to say, the k_{yt} values are constant for moisture deficits ranging up to about 50 percent of maximum potential evapotranspiration. A LOTUS spreadsheet was used to estimate the actual yield that would be realized under various alternative moisture availability regimes. Appendix 3, Table 1 is an example of that spreadsheet calculated for sorghum and millet at the Kita location with a rainfall pattern that equals the long term average and a low rate of infiltration of precipitation into the root zone of the soil.

Rainfall and Infiltration

The yield-moisture stress model was used to estimate yields under weather situations such as occur at three locations in Mali. Kita, located in southwestern Mali, has a long run average precipitation of 1080mm per year. Segou, in central Mali, has a long run average rainfall of 720mm per year. Hombori, located in eastern Mali, has an average rainfall of 412mm per year.

Appendix 3, Table 1. Water balance and yield reduction computations for Sorghum and Millet, with schedule S1 (early planting) and low efficiency of water infiltration (+-40%).

TM	DATES	GROWTH STAGES	DAYS PER GROWTH STAGE:	DAYS PER TIME PERIOD:	ETo PER DAY: (MM/TM)	ETo PER TM (MM/TM)	Kc FACTOR	ETm (MM/TM)	RAIN-FALL (MM/TM)	INFILTR. FACTOR (LOW)	EFFRAIN (MM/TM)	MOIS. DEF. (% TM)	MOIS. DEF. (%Tot.)	kY YIELD FACTOR	ADJ. YIELD FACTOR	YIELD RED. (%)	BASE YIELD (KG/HA)
TM-07	12/1-4/15			135	8.9	1201.5	0	0	0	0.60	0				0.25		1250
TM-08	- 5/1			15	9.0	135.0	0	0	14.3	0.60	8.58	0	0	0		0	
TM-09	- 5/15			15	8.7	130.5	0	0	5.2	0.60	3.12	0	0	0		0	
TM-10	- 6/1	ESTABLISH	15	16	8.3	132.8	0.30	39.84	19.9	0.60	11.94	0	0	0		0	
TM-11	- 6/15	VEGETATIV	30	15	7.7	115.5	0.75	86.63	94.7	0.40	37.88	0.70	0.044	0.20		0.0350	
TM-12	- 7/1	"		15	7.0	105.0	0.75	78.75	68.0	0.40	27.20	0.56	0.077	0.20		0.0281	
TM-13	- 7/15	FLOWERING	30	15	6.3	94.5	1.00	94.50	35.0	0.41	14.35	0.65	0.082	0.20		0.0327	
TM-14	- 8/1	"		16	5.8	92.8	1.00	92.80	173.7	0.41	71.22	0.85	0.127	0.55		0.1166	
TM-15	- 8/15	YIELD FOR	45	15	5.5	82.5	0.75	61.88	205.3	0.33	67.75	0.23	0.034	0.55		0.0319	
TM-16	- 9/1	"		16	5.5	88.0	0.75	66.00	176.4	0.33	58.21	0	0	0.45		0	
TM-17	- 9/15	"		15	5.7	85.5	0.75	64.13	101.3	0.38	38.49	0.12	0.012	0.45		0.0132	
TM-18	-10/1	RIPENING	15	15	6.1	91.5	0.50	45.75	18.4	0.38	6.99	0.40	0.041	0.45		0.0449	
TM-19	-10/15			15	6.5	97.5	0	0	30.5	0.33	10.07	0.85	0.061	0.20		0.0423	
TM-20	-11/1			16	6.8	108.8	0	0	2.5	0.33	0.83	0	0	0		0	
TM-21	-11/15			15	6.8	102.0	0	0	3.0	0.40	1.20	0	0	0		0	
TM-22	-12/1			15	6.7	100.5	0	0	0	0.40	0	0	0	0		0	
TM-23	-12/15			15	7.0	105.0	0	0	0	0.60	0	0	0	0		0	
			135					630.265	948.2		349.24		0.479			0.345	

Daily precipitation records for each of these locations were obtained from the Evapotranspiration Laboratory at Kansas State University, and other climatic information was obtained from Hargreaves and Samani, 1986. The daily precipitation record was aggregated into half-monthly time periods that correspond with the twenty-four periods in the yield-moisture stress estimating model, as shown in Appendix 3, Table 2.

The yield-moisture stress model was used to predict yields at each of the planting dates for the crops for each of the years of weather record. Thus, there was an estimate of the yield that could be expected from early, mid-season, or late plantings of each crop if weather occurred that was practically equal to weather in one of the years during the period of record. The resulting yields were arrayed from lowest to highest over the entire period of record and summarized by quartiles. The yields of sorghum associated weather at the Kita station are presented in Appendix 3, Table 3.

Estimates of yield that could be expected if patterns of precipitation recur provide a weather rating index that incorporates much more information than can be gleaned from, for example, the total seasonal precipitation or the precipitation in a critical time period during a cropping season.

Appendix 3, Table 2. Precipitation by time period. Kita weather station.

	ANNUAL PRECIP	PRESEAS RAIN	FIRST + SECOND	REST SEASON	PRECIPITATION by HALF-MONTH INTERVALS PRE-TH-8	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Quartil 1																				
MIN.forS1	825.0	21.8	224.0	579.2	0.3	6.9	1.0	13.6	141.2	82.8	26.9	163.9	146.6	100.0	55.3	34.2	25.0	19.4	0.0	7.9
MAX.forS1	1005.5	38.0	77.0	890.5	5.0	33.0	63.0	14.0	102.0	46.0	48.0	110.0	123.0	138.5	157.0	82.0	68.0	16.0	0.0	0.0
Avg.	889.9	36.9	136.6	716.3	5.1	8.7	15.1	23.2	67.0	65.9	63.2	110.5	131.1	126.5	116.2	84.6	56.7	13.9	1.1	1.1
STD	96.1	21.0	39.1	111.2	7.6	13.5	19.8	29.1	36.1	20.1	22.9	41.8	43.1	34.2	62.7	51.7	45.7	10.1	3.1	2.3
Quartil 2																				
MIN.forS1	1052.4	42.6	259.8	750.0	0.0	5.0	21.0	16.6	130.0	129.8	50.0	189.0	55.0	244.0	75.0	45.0	80.0	9.0	3.0	0.0
MAX.forS1	1069.5	118.9	111.3	839.3	54.8	13.1	8.3	42.7	73.3	38.0	80.6	191.7	114.3	161.5	198.3	52.1	18.4	0.7	0.0	21.7
Avg.	1030.1	56.3	186.8	786.9	8.5	8.0	13.0	17.9	77.5	88.2	95.1	131.8	142.2	186.3	121.8	67.8	45.5	21.8	2.1	2.5
STD	116.9	33.0	44.0	109.9	15.4	10.4	10.7	11.3	34.5	32.1	32.2	43.4	44.4	60.6	37.8	39.7	51.0	50.4	2.9	6.3
Quartil 3																				
MIN.forS1	1084.7	39.5	275.8	769.4	16.5	0.0	0.7	22.3	74.9	200.9	50.6	146.5	183.7	121.3	162.1	68.3	31.8	5.1	0.0	0.0
MAX.forS1	1268.5	36.0	206.0	1026.5	2.0	2.0	28.0	4.0	93.0	113.0	196.5	128.0	180.5	183.5	108.0	77.0	52.0	59.0	42.0	0.0
Avg.	1170.2	42.5	146.1	981.7	2.0	4.4	17.6	35.0	62.1	76.5	140.6	140.9	184.2	196.8	131.2	89.2	53.1	21.1	15.6	0.0
STD	111.5	27.4	52.4	139.0	4.6	9.3	15.1	23.6	18.7	53.5	56.1	31.6	58.5	79.0	39.2	29.4	42.7	23.1	23.9	0.0
Quartil 4																				
Min.(S1)	1258.5	11.5	102.6	1144.4	0.0	0.0	4.5	7.0	64.6	38.0	162.5	145.2	191.0	300.9	110.7	156.1	55.0	23.0	0.0	0.0
Max.(S1)	1507.6	49.8	217.2	1240.6	3.5	12.6	4.2	29.5	149.5	67.7	208.0	235.4	222.1	224.6	129.5	28.9	49.9	13.5	28.7	0.0
Avg.	1347.5	53.1	158.1	1136.3	10.2	13.4	22.7	39.6	92.0	87.4	140.6	184.7	185.1	214.7	142.8	110.7	66.4	27.9	8.0	1.3
STD	148.4	25.7	43.6	168.9	13.5	24.4	19.7	22.6	29.6	38.9	45.1	30.1	49.7	69.3	51.4	29.5	32.7	32.3	11.0	2.8
TOTALS																				
AVERAGE	1103.9	47.1	156.9	899.9	6.4	8.5	17.0	28.7	74.3	79.3	109.1	141.0	160.1	180.3	127.6	87.5	55.1	21.0	6.7	1.2
MINIMUN	766.0	2.0	77.0	569.3	0.0	0.0	0.0	0.0	4.0	7.0	26.9	30.7	41.3	44.0	22.8	15.6	2.1	0.0	0.0	0.0
MAXIMUN	1619.8	118.9	275.8	1448.8	54.8	82.6	73.3	107.6	149.5	200.9	254.9	235.4	296.0	324.1	278.6	168.0	187.7	180.0	77.1	21.7
ST. DEV.	205.4	28.3	48.9	210.7	11.6	15.6	17.1	24.2	32.5	39.2	52.4	45.8	55.0	71.0	49.8	41.7	44.4	32.8	14.6	3.8

Appendix 3, Table 3. Estimated yield and yield reductions by quartiles at three planting times, low infiltration efficiency rate, and long run average weather at three infiltration rates. Kita weather region in MALI (West Africa).

	Yield			Reduction			Precipitation
	S1	S2 (kg)	S3	S1	S2 (percent)	S3	(mm)
Quartil 1							
MIN.	703	712	628	0.44	0.43	0.50	825
MAX.	774	818	746	0.38	0.35	0.40	1006
AVG.	739	763	714	0.41	0.39	0.43	890
STD.	21	54	72	0.02	0.04	0.06	96
Quartil 2							
MIN.	777	810	724	0.38	0.35	0.42	1052
MAX.	880	855	732	0.30	0.32	0.41	1070
AVG.	829	831	777	0.34	0.34	0.38	1030
STD.	41	56	73	0.03	0.05	0.06	117
Quartil 3							
MIN.	882	894	784	0.29	0.28	0.37	1085
MAX.	939	918	854	0.25	0.27	0.32	1269
AVG.	906	894	840	0.28	0.28	0.33	1170
STD.	19	40	67	0.02	0.03	0.05	112
Quartil 4							
MIN.	939	971	937	0.25	0.22	0.25	1259
MAX.	1105	1075	956	0.12	0.14	0.24	1508
AVG.	982	979	901	0.21	0.22	0.28	1347
STD.	55	57	70	0.04	0.05	0.06	148
Totals for Efficiency 1							
AVG.	861	864	806	0.31	0.31	0.36	1104
MIN.	703	700	627	0.12	0.14	0.21	766
MAX.	1105	1075	991	0.44	0.44	0.50	1620
STD.	97	95	99	0.08	0.08	0.08	205
Totals for Efficiency 2							
AVG.	1038	1062	989	0.17	0.15	0.21	
MIN.	878	910	788	0.04	0.02	0.06	
MAX.	1197	1221	1171	0.30	0.27	0.37	
STD.	90	90	101	0.07	0.07	0.08	
Totals for Efficiency 3							
AVG.	1111	1136	1067	0.11	0.09	0.15	
MIN.	960	985	884	0.01	0.00	0.01	
MAX.	1234	1250	1241	0.23	0.21	0.29	
STD.	74	77	91	0.06	0.06	0.07	

Season-by-season yields recognize that the pattern of rainfall occurring during the season has an effect on yield over and above the effects that may arise from the total rainfall. The difference shown in Appendix 3, Table 3 between the yield averaged over all the years and the yield that would be expected if exactly average weather occurred throughout the year illustrates this principle. The long run average of yields expected to occur given the various uneven weather patterns experienced at Kita is approximately 8 percent less than the yield that would be expected if exactly the long run average weather occurred in a given year.

The amount of moisture available for plant growth is affected by the infiltration and water-holding capacity of the soil as well as by the amount of precipitation that falls. The serious crusting problems that occur, especially in the rainfall zones of 700mm and above, are reflected in a very low set of infiltration rates being appropriate for conventional farming practices in the higher rainfall zones. The low infiltration rate assumes that approximately 40 percent of the moisture that falls is actually available in the root zone for the plant. The infiltration rate varies somewhat from one time to the next during the year as normal tillage and groundcover from a growing crop tend to improve the rate of infiltration over what would be the case on bare, untilled ground. Medium (approximately = .6) and high (approximately = .8) infiltration rates are also investigated. These higher rates might be obtained through improved tillage or through structures such as tied ridges or other devices that hold the water on the land and allow more time for infiltration.