PURDUE UNIVERSITY
International Programs in Agriculture

PN-AAN-302
ISN= 45815

IPIA

SEMI-ARID FOOD GRAIN RESEARCH AND DEVELOPMENT PROGRAM

FARMING SYSTEMS RESEARCH UNIT

(USAID Contract AFR-C-1472)

AN APPLICATION OF WHOLE-FARM MODELLING TO NEW TECHNOLOGY EVALUATION, CENTRAL MOSSI PLATEAU, BURKINA FASO

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February 1986

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March 1986

Third Draft

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PREFACE

Whole-farm modeling has been used by SAFGRAD/Purdue University in their Farming Systems Research in Burkina Faso for the economic evaluation of agricultural technology. This report contains documentation of a farm model developed for the Central Mossi Plateau of the country along with its application in evaluating tied-ridges. Further applications of the model in evaluation of fertilizer, animal traction and tied ridging technologies can be found in Roth and Sanders, "An Economic Evaluation of Selected Agricultural Technologies with Implications for Development Strategies in Burkina Faso", 1984; and Nagy, Ames and Ohm, "Technology Evaluation, Policy Change and Farmer Adoption in Burkina Faso", 1985.

Introduction

The improvements in agricultural productivity brought about by the "Green Revolution" around the world appear to have largely missed sub-Saharan Africa. Over the past two decades, food production in most developing countries expanded faster than their populations while food production per capita in most West African countries declined (USDA, 1981; World Bank, 1981).

The problems experienced by the agricultural sector of Burkina Faso[1] are indicative of the food situation emerging on the continent. Agriculture provides the livelihood for over 80 percent of Burkina's 5.6 million population. Over the past several decades, however, agricultural productivity has fallen. USDA (1981, p. 280) for instance, estimates the average "indices of food production" in 1976-78 as only 67 percent of the 1961-65 base period. By the late seventies, caloric intake per capita was estimated at 71 percent of recommended daily requirements (USDA, 1981, p. 280).

Farming Systems Research (FSR) is one approach international donors in collaboration with host countries have taken to improve agricultural productivity. One of its principal objectives is to identify constraints to increased food production and develop new agricultural technologies to alleviate these. The research is multi-disciplinary involving social scientists, agronomists, plant breeders, and other agricultural scientists. It focuses on the structure and dynamics of the farming system and problems of identification, development, and dissemination of technologies appropriate to increasing agricultural incomes of rural producers.

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[1] Burkina Faso was formerly named Upper Volta.

In the process of technology evaluation the economist has several roles. One involves examining the structure of household production and consumption to identify constraints to higher productivity. Another involves the economic evaluation of new technologies (designed to alleviate these constraints) in order to provide feedback to researchers for technology improvement. Good models of household production and consumption behavior are instrumental in performing these functions. In the first case, modelling helps integrate data collection and analysis and provides insight into the structure of the farming system. Once models are developed, they may be used as prescriptive tools to evaluate the potential impacts of new technology, introduced into the system.

The argument is frequently made that development of household-firm models require detailed data collection. This is particularly true in Africa where data limitations are acute. Data analyses often never reach the point where modelling is done, however, due to time limitations (common to the limited time frame of research projects). Moreover, modelling is useful for prioritizing data collection efforts. By developing models in the early stages of research, direction is given to better empirical research and in turn, to better models later on.

In this paper, a "whole-farm" model is developed for a representative farm on the Central Mossi Plateau of Burkina Faso. Data for the model are taken nearly entirely from published research in Burkina Faso, a country where data limitations are perceived to be "acute". The analysis serves two purposes: a) to highlight areas where the empirical research is weak and merits further research; and b) to demonstrate the usefulness of the model and methodology for technology evaluation, given data limitations.

This paper is organized in the following manner. In the first section, three different approaches to technology evaluation -- "expert" opinion, partial budgeting, and mathematical programming -- are considered. Next, characteristics of farming households and agricultural technology on the Central Plateau are described. Potential new technologies and issues relevant to their evaluation are also discussed. A model of household production is then presented. In that section, an overview is provided of model specification, drawing heavily on an attached set of appendices for model structure and empirical development. Then, issues dealing with model validation and performance are covered, followed by the economic evaluation of a new tied ridging technology in the final section.

Assessment of Various Approaches Used to Evaluate new Technology Adoption

The role of the agricultural economist in FSR is to identify those elements of farmer behavior, resource endowments and structure of the household (as a production and consumption unit) that constrain production and are amenable to new technological developments. New agricultural technologies (capable of increasing crop yields) have been found in many parts of the world. These new technologies typically require a package of increased inputs and different management practices which may or may not be compatible with the existing farm operation. Increasing yields is a necessary but insufficient condition for adoption. New technology must also offer farmers feasible economic alternatives that fit into the whole farm operation. A yield increase is not sufficient. A new technology must also be profitable.

The economist's role serves two purposes: First, the economist, along with other social scientists, needs to provide an understanding of the farmer's decision making process and of constraints faced by that farmer in coming to his decisions. Knowledge of farmers' behavior and their resource constraints will aid in identifying the key problems to be addressed in agricultural research. Second, that knowledge may be used to anticipate reactions of farmers to the introduction of new agricultural technologies. Armed with that knowledge, research priorities can be set and emerging prospects evaluated to determine their compatibility with the farming system.

Assessing the integration of a technological package into the whole farm system and predicting farmer reaction may be approached using several methodologies. The simplest and most common approach is for "experts" to conduct descriptive studies of farming systems and using their judgement, set research priorities. Baseline socioeconomic studies provide the necessary information. There are several problems with this approach. First, the analysis is highly dependent on the judgement of the analyst and is difficult to extend to "non-experts". Second, "experts" incorporate implicitly the framework of their own discipline and probably their specialty within that discipline. For this reason, recommendations of "experts" tend to fall within their disciplinary boundaries. The farming system is complex and requires a more structured analytical framework to integrate data analysis for evaluation. Furthermore, a formal framework provides a guide for prioritizing data collection.

The process of modelling farmers' economic behavior can be carried out at many levels and for several purposes. At a minimum, the economic model must provide the general framework for observation and analysis. It may however be extended and formally applied to evaluation, if interpreted with care, to supplement, constrain, and challenge "expert" judgement.

The simplest approach to economic modelling is partial budgeting. Information required by this approach includes an enumeration of all inputs required by existing and new technologies plus outcomes. Values (prices) are assigned to each input and output, and net present value or profitability is compared between the existing and new technologies. If efficient markets exist for inputs and products, then one may evaluate the profitability of a new technological alternative at market prices. This approach is comparable to a cost-benefit analysis of the new technology and represents a standard evaluation technique.

Several problems arise using the partial budgeting approach, due to the manner in which price and quantity information are treated. The assumption that markets are efficient and prices accurately reflect social values is questionable. Efficient markets do not always exist. Market imperfections and government interventions may distort market prices from true social opportunity costs.[2] Nevertheless, sensitivity analysis can always be employed to test the sensitivity of the partial budget solution to varying price schemes. More critical problems arise when prices are unknown (due to non-existent markets) and/or determined endogenously by the farm's operations. Markets do not generally exist for two factors in Burkina Faso -- land and labor -- creating problems in this area.

In much of West Africa, land is allocated by social custom. In the absence of a market, explicit prices are non-existent. Yet, land prices are

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[2] The cost-benefit literature suggests use of border (international) prices as a proxy for social value, as they represent the true opportunity cost of traded products and resources facing an open international market. For a landlocked country like Burkina Faso, for which many products or resources are not traded, border prices may not represent the true social opportunity costs of resources.

essential for determining how different land types are allocated among crops and for evaluating the profitability of a new technology. Since the implicit value of different land types is determined within the system of household production as a function of soil fertility levels, input requirements, crop technologies employed and prices, it is difficult to estimate land values a priori without assessing the relationship between these variables.

Labor behaves as a fixed resource for some periods during the year but acts like a variable resource in other periods. The market for farm labor in Burkina Faso is "thin", existing mainly during the non-bottleneck labor periods of the agricultural season. During periods of peak labor demand, (planting and first weeding of major cereals), labor is nearly impossible to hire, as families are working full time on their own fields. Shadow prices of labor during these peak periods are believed to be considerably higher than the wage rates observed during the off-season. The use of a market wage rate rather than the appropriate shadow price of labor will lead to biased estimates of profitability, particularly in assessing technologies that alter the seasonal flow of labor (e.g., tied ridging and animal traction). The appropriate wage bill is derived from the seasonal distribution of labor weighted by its shadow price.

Another problem often raised in this context is the effect of risk on farmer behavior. Rather than maximizing profit, farmers may be adopting strategies to minimize the risk associated with their decisions. For example, the farmer may wish to avoid increasing debt and its associated long run costs or may base his plans on minimizing the ill effects of drought. Partial budgeting simply charges a risk premium to investment cost, missing important crop interactions and the possibility of reducing risk by diversifying the crop mix.

A methodology useful for treating these problems is linear programming. This approach is similar to the partial budgeting approach in that farmers are still assumed to be rational maximizers. However, linear programming explicitly models the farmer's optimization problem. Therefore, more complex objectives involving risk avoidance may be incorporated. Optimization is determined subject to the resource endowments of farmers. This means the fixed resource problem is explicitly treated and estimates of the value (price) of resources (e.g., land and labor) are implicitly considered. This approach allows interactions between crops and crop mixes and indicates the amount of land to be allocated to each crop activity. Sensitivity analysis may be used to examine alternative assumptions regarding prices, technical requirements, or farm endowments.

Linear programming models of varying degrees of sophistication have been used to model farmer behavior. Many of the LP models constructed for developing-country farmers have been extremely complex, as the researchers have sought to build general purpose models addressing virtually all issues relevant to farmer behavior. The costs and applicability of such unfocused models has brought about a negative reaction among development analysts. An objective of this research is to demonstrate that simple models focusing on the critical issues can be powerful analytical tools.

Farming Systems on the Central Plateau of Burkina Faso[3]

The Central (or Mossi) Plateau covers approximately one-third of the land area of Burkina Faso. Approximately 60 percent of the population of the country is concentrated on the Plateau.[4] Rainfall, 600 to 900 mm. annually, is concentrated in the three to four month rainy season (June to September). Most agricultural activity occurs at this time.

The principal crops, red and white sorghum and millet, are grown mainly on village and bush fields of low fertility. Small areas of maize are planted on highly manured plots immediately surrounding the household compound. Rice is cultivated in lowland areas. Cowpeas are predominantly intercropped with millet and sorghum.

Over 85 percent of the cropped area on the Central Plateau is in cereal crops (Swanson, 1981; SAFGRAD-FSU, 1982; Kabore, *et al*., 1983; Ancey, 1974). Sorghums and millet are the main staples, although maize provides an important supplement during the *soudure* (hungry season). This period corresponds to the month prior to harvest of the main sorghum and/or millet fields when grain stocks can be depleted. Most of the millet and white sorghum (80-95 percent) are stored at harvest for consumption during the year. White sorghum is usually preferred because it can be stored 2 to 3 times as long as millet, according to farmers. Red sorghum is used for beer production and livestock feed, but may be used for human consumption as well. Small areas of groundnuts, bambara nuts and cotton are cultivated as "cash" crops, especially by wives and sons of the household head on "private" fields.

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[3] Appendices 1 through 7 present empirical findings on farming systems on the Central Mossi Plateau.

[4] The World Bank estimates man-land ratios of 30 people/km^2 on the Central Plateau compared with 12 people/km^2 for the rest of the country.

Family farms are small, 4 to 8 hectares. Hand tillage and donkey traction are the two most common forms of tillage technology. Oxen, while stronger and more efficient at land preparation, also require more feed. It appears that the opportunity cost of pasture areas is too high on the Central Plateau to support oxen technology.[5] Hired labor generally accounts for less than 10 percent of total labor on the farm.

Soil fertility is low. High population pressure has contributed to diminished land fallow in the farming system and to declining soil fertility and yields. Organic fertilizer is applied largely near household compound areas for maize production but to only a limited extent on the principal cereal fields (Bonkian, 1980). Use of chemical fertilizers is rare and when applied is less than 50 kg./ha. (ICRISAT, 1980; Lassiter, 1981; and Singh, et al., 1983).

Absolute yield levels for the basic cereals are low. Millet yields are 300 to 500 kg/ha., sorghum 400 to 700 kg./ha., and maize yields 900 to 1200 kg/ha. on the more fertile compound areas. Yields of cowpeas are generally low due to low planting densities and susceptibility to insect attack. Yields of other grain legumes (groundnuts and bambara nuts) range from 300 to 500 kg./ha. (Singh, et al., 1983, p. 28; World Bank, 1982).

To meet the minimum consumption needs of Burkina Faso's growing population, improvements in productivity of land and labor will be required. High yielding varieties have been available on the experiment station for some time. ICRISAT's E-35-1 sorghum has yielded 3.5 to 4 metric tons per hectare

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[5] Donkey traction is more common on the Central Plateau while oxen traction is more prevalent in the west and southwest areas of Burkina Faso. Roughly 21,000 oxen teams, 3,000 horse teams, and 24,000 donkey teams were in use in Burkina Faso in 1978 (MInistry of Rural Development, various O.R.D. Annual Reports).

under experimental conditions. IRAT has developed new varieties of sorghum, maize, and millet; its maize varieties have obtained 3 metric tons per hectare at the experiment station. Cowpeas yielding 1.5 to 2 metric tons per hectare have been obtained by IITA under experimental monoculture conditions (Singh, et al., 1983).

The farming systems project of SAFGRAD-FSU has taken new varieties and other improved technologies and put them into trials on farmers' fields. In agronomist managed trials, yields of 1 to 2 metric tons per hectare of sorghum and 2 to 3 metric tons per hectare of maize have been achieved (Kaylen, 1982, p. 5; SAFGRAD-FSU, 1983; SAFGRAD-FSU, 1984). Unfortunately, these new varieties have had little impact at the farm level (Stoop, et al., on sorghum, 1982, p. 522).

Improving soil fertility is critical to increasing cereal yields. The increased use of inorganic fertilizers, however, will require better water retention to reduce the risk associated with the Burkina environment where water retention is poor and rainfall sporadic. The breakdown of the fallow rotation,[6] the failure to return organic material to the soil, and overgrazing all contribute to soil degradation, leading to crusting and increased run-off (Saunders, 1980, p. 15). Under these conditions improved water retention through land preparation or ridging can reduce the erosive effects and lead to higher soil productivity. Combining the use of fertilizer and soil ridging may be an economic alternative for increasing cereal yields. The role of economic modelling is to take these agronomic results and evaluate them in the whole farm context.

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[6] The soils on the Central Plateau are generally sandy and shallow. On these fragile soils with their tendency for the topsoil to erode away and form a crust, an adequate fallow could require 10 to 15 years (Hammond, 1966, p. 28).

Model Specification

A "simplex tableau" representing the structure of the farm model is shown in Figure 1. The tableau presents the mathematical formulation of the farm problem. The first row corresponds to the objective function of the producer. The following rows denote resource constraints and technical requirements of the farming operation. Columns in the tableau represent the set of crop enterprises (technologies) the farmer may choose in maximizing his utility.

The decision maker[7] is assumed to be a simple profit maximizer, maximizing the function:

$$(1) \quad \max \Pi = \sum_k P_k Q_k - \Sigma \gamma_d Z_d \quad (k = 1, \ldots, S, \; d = 1, \ldots, D)$$

He maximizes the gross value of production $\sum_k P_k Q_k$ (sales plus value of output consumed by the household) less expenditures for modern inputs $\Sigma \gamma_d Z_d$. Prices P_k are output prices associated with production of $k = 1, \ldots, S$ commodities, Q_k. In all, six commodities may be produced including red and white sorghum, millet, maize, cowpeas, and groundnuts.

Input prices, γ_d, correspond to the set of modern inputs Z_d, $d = 1, \ldots, D$. For hand tillage technologies, land and labor are the only inputs. Their costs are derived implicitly from land and labor constraints

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[7] Consider the decision maker to be the household head and area cultivated to be the area under his control. In reality, the household head allocates small parcels of land to other workers in the household to do with as the workers choose. Cropping patterns on these "private" fields are outside the control of the household head. These fields are normally planted in groundnuts, okra, bambara nuts, and roselle while fields under the control of the household head are mainly devoted to cereal production (Singh, et al., 1983). Private fields represent a relatively small fraction of total area (i.e., 10-15%) though the assumption of only one decision maker may still bias results.

Figure 1: Farm Model Used to Evaluate New Technology Adoption

	Hand Tillage, X^m_{ji}				Donkey Tillage, X^d_{ji}				Ox Tillage, X^o_{ji}				Production, QK	Fertilizer, FERT	Donkey, DK	Oxen, OX	Manure, MNRc; Manure, MNRr; Manure, MNRw	RHS
Land Type	Cmpd	RS Land	WS Land	Bush Land	Cmpd	RS Land	WS Land	Bush Land	Cmpd	RS Land	WS Land	Bush Land						
Crop Activities	sole crop and crop mixture $j_1 \ldots j_{27}$				sole crop and crop mixtures $j_{28} \ldots j_{54}$				sole crop and crop mixtures $j_{55} \ldots j_{81}$									
Max Z													C_{H_k}	$-\gamma^w$	$-\gamma^d$	$-\gamma^o$		
Family Labor 1 … Family Labor 9	A^m_{ij}				A^{md}_{ij}				A^{mo}_{ij}						h^d_i	h^o_i		$MHR_i * MA + FHR_i * FA$
Donkey Labor 1 … Donkey Labor 9					A^d_{ij}										OHR_i			0
Oxen Labor 1 … Oxen Labor 9									A^o_{ij}							OHR_i		0
Yields	$-Y^m_{jk}$				$-Y^d_{jk}$				$-Y^o_{jk}$				1					0
Consumption													-1_k					$-G_k$
Compound Land	1 1 1				1 1 1				1 1 1								$-e^c$	T_c
High Quality RS Land		1 1 1				1 1 1				1 1 1							$-e^r$	T_r
High Quality WS Land			1 1 1				1 1 1				1 1 1						$-e^w$	T_w
Bush (Millet) Land				1 1 1				1 1 1				1 1 1						T_b
Maximum Donkeys															1			DK
Maximum Oxen																1		OX
Manure Supplied															$-m^d$	$-m^o$	1 1 1	0
Fertilizer	$-W^m$				$-W^d$				$-W^o$					1				

incorporated in the model. In this case, the producer's objective function reduces to maximization of total value of production. When animal traction and chemical technologies are considered, input costs for traction teams and fertilizer are incurred. Levels of output Q_k and inputs Z_d are determined endogenously by the optimization procedure. Market prices for P_k and γ_k in the analysis are given in Appendix 1.

Three types of tillage operations are permitted in the model: hand tillage, hand tillage combined with donkey traction, and hand tillage plus oxen traction. Animal traction is an imperfect substitute for hand tillage. When animal mechanization is used, some manual labor (besides driving the team) is still required for intra-row weeding and cleaning-up operations. For sake of definition, any of these three tillage operations are termed "traditional" technologies. The incorporation of tied ridges and fertilization in the model are later referred to as "modern" technologies.

Output of commodity Q_k, $k = 1, \ldots, S$ may be produced with varying agronomic techniques. Crops may be grown either in sole stands or in mixtures with other cereals or cowpeas. Intercropping is commonly observed on the Mossi Plateau, especially the mixing of cereals with cowpeas.[8] Groundnuts, however, are rarely grown in association with other crops. Four types of land are included and crops are allocated to land based on their comparative advantage. (Land types are discussed in a subsequent section.)

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[8] Singh, et al. (1983) report the percentage of crop area cultivated in mono-culture, in combination with other cereals, and intercropped with cowpeas as 13.3, 6.6, and 63.9 percent respectively for millet, 27.3, 15.2, and 33.3 percent for red sorghum, 10.0, 5.0, and 85.0 percent for white sorghum, 9.3, 37.2, and 0.0 percent for maize, and 46.0, 0.0, and 0.0 percent for peanuts (see also Kabore, Lebene, and Matlon (1983) and McIntire (1982)).

Table 1 shows the set of crop enterprises X_j, incorporated in the model. Sole crops and mixtures shown in the table are crop enterprises commonly observed on the Central Mossi Plateau. Technical substitution possibilities are incorporated among different crops, among sole crops and mixtures and among soil types. Substitution possibilities among maize and sorghum enterprises are more prolific on higher quality soils where they hold a yield advantage. Substitution among millet activities is more prolific on lower quality soils where it is normally cultivated. In total, 27 different production activities are possible for each type of traction system. Given three alternative traction systems, there are 81 possible production activities.

The derived demand and supply of land resources are defined by

$$(2) \quad \sum_j X^m_{jl} + \sum_j X^d_{jl} + \sum_j X^o_{jl} \leq T_l + e_l{*}MNR \qquad \begin{matrix}(j=1, \ldots, 27)\\(l=4)\end{matrix}$$

The demand for land type 'l' is derived from cultivation of crop enterprises X^m_j, X^d_j, and X^o_j, j = 1, ..., 27. The superscripts 'm', 'd', and 'o' refer to manual, donkey, and oxen tillage technologies, respectively. The supply of land, T_l, represents endowments of land type 'l' owned or controlled by the household head. No land can be rented so endowments, T_l, represent fixed resources. Four types of land are included in the model: (a) high quality land adjacent to the family's living quarters; (b) higher quality village and bush soils referred to as Red Sorghum land; (c) lower quality village fields referred to as White Sorghum land; and (d) poor quality bush fields (see Appendix 2 for derivation of the soils classification scheme). The farm by assumption has fixed endowments of the first three land types but unlimited bush land at its disposal. The dual prices (shadow prices) associated with right-hand-side (RHS) resources T_l,

Table 1: Cropping Activities Included in the Representative Farm Model

Land Type	No.	Primary Crop	Secondary Crop
Compound	1	Red Sorghum	
	2	White Sorghum	
	3	Red Sorghum	White Sorghum[a]
	4	Maize	
	5	Maize	Red Sorghum[a]
Red Sorghum	6	Red Sorghum	
	7	Red Sorghum	Cowpeas
	8	White Sorghum	
	9	White Sorghum	Cowpeas
	10	Maize	
	11	Red Sorghum	Maize[a]
White Sorghum	12	Red Sorghum	
	13	Red Sorghum	Cowpeas
	14	White Sorghum	
	15	White Sorghum	Cowpeas
	16	Millet	
	17	Millet	Cowpeas
	18	White Sorghum	Red Sorghum[a]
	19	Millet	White Sorghum[a]
	20	Maize	
	21	Peanuts	
Millet	22	White Sorghum	
	23	White Sorghum	Cowpeas
	24	Millet	
	25	Millet	Cowpeas
	26	Millet	White Sorghum[a]
	27	Peanuts	

[a] Crop mixture is 75% primary crop and 25% secondary crop.

--present the marginal value of an additional hectare of land. These dual prices implicitly allocate crops (enterprises X_j) among land types based on profitability.

The expression e_l*MNR converts additional manure, MNR, from traction animals into additional supply of higher quality land. The term e_l technically defines the amount of land 'l', created (from bush land) with applications of manure, MNR. The specification is based on agronomic principles; applications of manure improve soil structure and fertility. Alternatively, activities, X_j, could be included to define the production function for manure, but at greater cost in terms of model size. The supply of manure is obtained from the expression:

$$(3) \quad MNR - m^d*DK - m^o*OX \leq 0$$

Terms m^d and m^o represent the recoverable amounts of manure from donkey's (DK) and oxen (ox), respectively.

The first ten rows pictured in Figure 1 represent constraints associated with stocks and flows of human labor. Technical coefficients, A_{ij}, represent the number of hours required per hectare in period 'i' for crop enterprise X_j. For each period 'i', the derived demand and supply of labor can be represented by the equation

$$(4) \quad \sum_j A^m_{ij} X^m_j + \sum_j A^{md}_{ij} X^d_j + \sum_j A^{mo}_{ij} X^o_j \leq MHR_i*MA + FHR_i*FA + h^d_i*DK + h^o_i*OX$$

$$(i = 1, \ldots, 10;\ j = 1, \ldots, 27)$$

Each term on the left side of the inequality represents demand for labor in conjunction with the three traditional technologies. The human labor requirements in period i for crop enterprise X^m_j (hand tillage) are represented by A^m_{ij}. Similarly, the human labor requirements in period i for crop enterprise X^d_j and X^o_j (tilled with donkey and oxen traction) are A^{md}_{ij} and A^{mo}_{ij}, respectively. The demand for human labor then in period 'i' is derived from the sum of time worked on various crop enterprises (X^m_j, X^d_j, X^o_j, $j = 1, \ldots, 27$).

Each constraint 'i' represents a period of the agricultural season. The first period, corresponding to the planting season, is 5-6 weeks in duration and covers planting of major cereal fields. Subsequent rows delineate periods of planting, first weeding, and second weeding, although timing of activities depends upon the type of crop enterprise, X_j. Constraints corresponding to the critical periods of first weeding are made weekly in duration to better capture the costs of labor tradeoffs. For further details on derivation of labor flows and seasonality of labor, refer to Appendix 3.

The supply of labor is derived from the number of male adult (MA) and female adult (FA) "actives" in the household and amount of time each has available for farm work. No hiring of labor is permitted so labor supply represents a fixed resource. Male adults work MHR_i hours in period i and female adults, FHR_i hours. Labor availability is determined by the number of good field days in each period and number of hours that can be worked per day. (Refer to Appendix 2 for the derivation of number of active workers and Appendix 3 for rates of work intensity during period 'i'.) The dual prices associated with RHS labor resources, MHR_i*MA plus FHR*FA, are the marginal values of an additional hour of labor in period i. That is, they are the shadow wage rates imputed from the farms operations.

The terms h^d_i*DK and h^o_i*OX represent adjustments to household labor supply associated with ownership of animal traction. It has been observed that animal traction households possess larger family size and work force than non-AT households (Appendix 2). Terms h_i^d*DK and h_i^o*OX incorporate labor effects for differences in household size.

The demand and supply for donkey and oxen traction services are represented by equations

$$(5) \quad \sum_j A_{ij}^d X_{ij}^d \leq DHR_i{*}DK$$

$$(6) \quad \sum_j A_{ij}^o X_{ij}^o \leq OHR_i{*}OX$$

$$(i = 1, \ldots, 10; \quad j = 1, \ldots, 27)$$

Unlike farm equipment, animals have limited endurance and face labor constraints similar to humans in equation (4). It is assumed that animal traction households are experienced in the use of animal mechanization. That is, they are on the upper slope of the learning curve and are operating efficiently.[9] The number of hours worked by the donkey team on crop enterprise X_j is represented by the term A_j^d and the oxen team by A_j^o. The demand for animal traction services then is derived from work on crop enterprises X_j^d and X_j^o, respectively. Recall that time worked by humans (i.e., A_{ij}^{md} and A_{ij}^{mo}) was accounted for in equation (4).

The supply of animal traction services is determined by the amount of time traction animals can be worked in period 'i' (DHR_i and OHR_i) and number of traction teams (DK and OX). For details on the derivation of animal labor requirements and work intensity rates, see Appendix 5.

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[9] Both Jaeger (1983) and Cohen (1982) show the returns to animal traction to increase with experience in use. For our purposes here it is assumed that animal traction is adopted with the same level of efficiency as that achieved by an experienced animal traction household.

Production in the model is determined by the identity

$$(7)\quad Q_k - \sum_j \sum_k (Y^m_{jk}X^m_j + Y^d_{jk}X^d_j + Y^o_{jk}X^o_j) \leq 0$$

$$(k = 1, \ldots, 5; \quad j = 1, \ldots, 27)$$

The term Y^m_{jk} represents yields (k = 1, ..., S) of crop enterprise X^m_j; Y^d_{jk} refers to yields of crop enterprise X^d_j and Y^o_{jk} represents yields of crop enterprise X^o_j. Multiple commodities (k = 1, ..., S) may be produced per enterprise due to intercropping. Production of commodity Q_k then is the product of yields and area summed over j = 1, ..., 81 activities. Table 2 contains yield assumptions for hand, donkey, and animal traction technologies in the model, estimated from on-farm and experimental data in Appendix 4. Yield levels generally increase from lower to higher quality soils and with animal traction technologies.

The household has a minimum consumption requirement for maize. This is represented by the equation

$$(8)\quad Q_k \geq G_k$$

where G_k is the minimum level of maize required to feed the family during the soudure. During this period, cereal stocks are often low and the major sorghum and millet fields have not yet reached maturity. The household will generally plant enough maize (short-term varieties) to meet food needs during this time.

Linear programming is used to solve the producer's optimization problem. The amount of area and production of each crop is found such that net income is maximized subject to constraints (2) to (8). The algorithm calculates the opportunity cost (shadow price) for each resource, or what a profit maximizing farmer would be willing to pay to release one unit of the fixed factor. Sensitivity analysis may also be used to evaluate the

Table 2: Yield Levels for Sole Crops and Crop Mixtures by Type of Land and Traction Technology Assumed in the Farm Model.

Type of Land	Crop Mixture	Hand Tillage	Donkey Tillage	Oxen Tillage
Millet Land	W. Sorghum	310	325	335
	W. Sorghum/Cowpeas	310/35	325/20	335/20
	Millet	340	357	367
	Millet/Cowpeas	340/35	357/20	367/20
	Millet/W. Sorghum	255/78	268/81	275/84
	Peanuts	480	430	430
White Sorghum Land	R. Sorghum	420	470	483
	R. Sorghum/Cowpeas	420/45	470/27	483/27
	W. Sorghum	440	493	506
	W. Sorghum/Cowpeas	440/45	493/27	506/27
	Millet	410	460	472
	Millet/Cowpeas	410/45	460/27	472/27
	W. Sorghum/R. Sorghum	330/105	370/118	380/120
	Millet/W. Sorghum	308/110	345/123	354/127
	Maize	400	468	480
	Peanuts	520	470	470
Red Sorghum Land	R. Sorghum	600	702	720
	R. Sorghum/Cowpeas	600/55	702/35	720/35
	W. Sorghum	550	644	660
	W. Sorghum/Cowpeas	550/55	644/35	660/35
	Maize	650	793	813
Compound Land	R. Sorghum	850	1080	1105
	W. Sorghum	770	978	1000
	R. Sorghum/W. Sorghum	638/185	810/245	829/250
	Maize	1000	1320	1350

reliability of the data or to consider what outcomes are required for an activity to be profitable.

Validation of Model Results

Before assessing the impact of new agricultural technology on the farming system, an evaluation of model performance is needed. The process of validation is difficult because there is no counterpart to truly benchmark results.[10] All that can be done is compare solution results for various parameters with findings in farm studies taking account of the inter-farm variations that exist.

The base solution results for crop activities chosen by the model are given in Table 3. Information are presented on hectares cultivated in various sole crop and crop mixtures by land type and according to the type of tillage practices employed (e.g., hand, donkey, and oxen tillage).

Crop Activities: The crop activities chosen by the model are mostly consistent with observed far ing practices. Red sorghum and maize are primarily planted on the gner quality land, white sorghum on soils of lesser soil fertility whil illet and peanuts are grown on the poorest quality soils. Sorghums and millet are always planted in association with cowpeas, consistent with cropping patterns observed.

Table 4 shows the proportion of total area cultivated in various crops by type of traction technology. The cropping patterns generated by the model are compared with studies by Jaeger (1983) and McIntire (1981) to help validate results. The model appears to approximate cropping patterns quite

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10 When models are constructed from data in the field, the data themselves provide the benchmark. However, when models are constructed from limited data and secondary sources as here, no concrete benchmarks exist.

Table 3: Solution Values for Crop Activities by Type of tillage Traction (Base Model Solution)

Type of Land	Activity	Type of Tillage	Hand Solution	Donkey Solution	Oxen Solution
Compound	Red Sorghum	Hand	.01		
	Maize	Hand	.15	.16	.16
Red Sorghum	R. Sorghum/Cowpeas	Hand	.55		
	R. Sorghum/Cowpeas	Donkey		.09	
	Maize	Donkey		.55	
	Maize	Oxen			.71
White Sorghum	W. Sorghum/Cowpeas	Hand	.80		
	W. Sorghum/Cowpeas	Donkey		.80	
	W. Sorghum/Cowpeas	Oxen			.41
	Maize	Oxen			.39
Millet	Millet/Cowpeas	Hand	2.75	.82	1.82
	Millet/Cowpeas	Donkey		3.91	
	Millet/Cowpeas	Oxen			5.41
	Peanuts	Hand	.02	.17	.23
	Peanuts	Donkey		.07	
	Peanuts	Oxen			.84
Total Surface	White Sorghum		.80	.80	.41
	Red Sorghum		.56	.09	
	Millet		2.75	4.73	7.23
	Maize		.15	.71	1.26
	Peanuts		.02	.24	1.07
	Total		4.28	6.57	9.97

closely with the exception of several areas. First, maize tends to enter the model too strongly under all three traction scenarios. This result should be expected since the model maximizes profit with no accounting of risk. Maize is a high-risk crop relative to sorghums, millet, and to a lesser extent, peanuts. Second, red sorghum is underestimated in the donkey and oxen solutions due to the direct competition that exists with maize for higher quality land.

Peanuts also tend to be underestimated for the hand and donkey solutions for several possible reasons: First, our assumption that millet land is unlimited is probably unrealistic. If all land were constrained, a tendency would exist to intensify per unit of area with a shift made towards higher value crops such as peanuts. Second, the model reflects the decision making of the household head who devotes most land to cereal production because of his obligations to meet family food needs.[11] Decisions made by other family members on "private" fields which contain a higher proportion of peanuts are not incorporated in the model. Oxen solutions are difficult to validate because oxen traction studies on the central Mossi Plateau are limited.[12]

Total Area Cultivated: In Table 4, Jaeger and McIntire report total farm size to vary between 2.51 to 4.41 hectares for hand tillage households and 3.36 to 8.18 for donkey tillage households. These survey villages

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[11] Note that "private" fields are constrained in area since they are allocated to family members by the household head. Apparently, the higher proportion of peanuts reflects the strategy of maximizing returns per unit of area in order to meet family members cash needs.

[12] Activities involving oxen traction are to the most part synthesized or extrapolated from coefficients in the donkey traction model. Studies of oxen traction on the Mossi Plateau are not abundant due probably to the low level of application of the technology in the region.

Table 4. Cropping and Land Use Patterns Predicted by the Base Model Under Three Alternative Traction Scenarios.

Crops	Base Model Solutions			Jaeger (1983)		McIntire (1981)	
	Hand Tillage	Donkey Tillage	Oxen Tillage	Hand Tillage	Donkey Tillage	Hand Tillage	Animal Tillage
Millet	64.3	72.0	73.0	62.0	63.0	73.3	73.5
White Sorghum	18.7	12.2	4.1	15.4	18.5	6.4	8.6
Red Sorghum	13.1	1.4	--	12.7	8.6	13.1	8.6
Maize	3.5	10.8	12.6	2.0	2.4	2.0	1.8
Peanuts	0.5	3.7	10.7	5.4	5.5	4.4	6.0
Bambara Nuts				1.8	1.2	0.8	1.5
Rice				0.5	0.1		
Total Hectares Cultivated	4.28	6.57	9.97	4.41	8.18	2.51	3.36
Compound Land	.16	.16	.16				
Red Sorghum Land	.55	.63	.71				
White Sorghum Land	.80	.80	.80				
Millet Land	2.77	4.97	8.31				
Active Workers	6.0	7.5	8.0	4.71	6.64		
Residents	11.0	13.0	14.0			9.7[a]	10.9[a]
Area Cultivated/Worker	.71	.88	1.25	0.94	1.23		
Area Cultivated/Resident	.39	.51	.71			.26	.31

(Nakomtenga and Nedogo) are within close proximity to each other. Given this degree of variability (for a given technology), differences are difficult to reconcile. The model results here more closely follow the results of Jaeger for the village of Nedogo though the results suggest that the representative farm lies somewhere between the two.

Adoption of animal traction leads to an expansion of total area cultivated in the model solution. Since higher quality land types are assumed to be relatively fixed, the labor saving effects of animal traction result in expansion of millet on bush fields. If, on the other hand, a constraint were to be placed on the amount of area expansion that could take place, labor would substitute for land and higher value crops on millet land -- i.e., peanuts -- would enter the solution more strongly. Also, the area of red sorghum land increases slightly with animal traction. This results from the model allocating the additional manure from donkey and oxen to expansion of red sorghum area.

Shadow Prices of Fixed Resources: The shadow price or opportunity cost of a resource represents the amount the farmer would be willing to pay to purchase one additional unit. In the case where slack (unutilized) resources exist, the marginal value is zero. On the other hand, if a resource is constraining to the model solution, an amount greater than zero would be expected. Table 5, presents a summary of opportunity costs of resources for the "base" model solution:

- Human labor: The opportunity cost for labor is the amount that a simple profit maximizer would be willing to pay to acquire one additional hour of labor in period "i". The opportunity cost of labor for the hand tillage solution is 365 CFA/hour in period 5 (critical weeding period) and 181 CFA/hour in period 6. This is consistent

Table 5. Opportunity Costs of Resources Under Various Traction Scenarios (Base Model Solution).

Resources	Units	Hand Solution	Donkey Solution	Oxen Solution
Human Labor, Period 1	FCFA/Hr.	0	83	125
Human Labor, Periods 2-4	"	0	0	0
Human Labor, Period 5	"	365	347	339
Human Labor, Period 6	"	181	75	22
Human Labor, Periods 7-9	"	0	0	0
Donkey Labor, Periods 1-3	FCFA/Hr.		0	
Donkey Labor, Period 4	"		115	
Donkey Labor, Period 5	"		566	
Donkey Labor, Periods 6-9	"		0	
Oxen Labor, Periods 1-3	FCFA/Hr.			0
Oxen Labor, Period 4	"			293
Oxen Labor, Period 5	"			1251
Oxen Labor, Periods 6-9	"			0
Compound Land	FCFA/Ha.	31,273	29,570	32,602
Red Sorghum Land	"	25,232	19,983	21,384
White Sorghum Land	"	7,879	3,522	1,919
Millet Land	"	0	0	0
Donkey	FCFA/animal		52,819	
Oxen	"			141,003
Manure Supplied	FCFA/ton		2.208	2.364
Maize Consumption	FCFA/kg.	7.7	0	0

with statements of farmers that time of first weeding is the most labor constraining period, but tends to overstate the wage rates commonly reported in the literature (i.e., roughly 50 CFA/hour).[13] Labor markets in Upper Volta however are generally "thin" with virtually no labor hired during critical periods. The fact that farmers choose to work their own fields rather than work for others at this time suggests that a high value to labor exists.

- Effect of animal traction: Animal traction in Burkina Faso is generally used to perform weeding operations and less so for land preparation (i.e., plowing). Consequently, animal traction tends to smooth out the seasonal distribution of human labor worked on the farm. This is demonstrated in Table 5. Animal traction decreases the opportunity cost of human labor at the critical weeding bottleneck -- from 365 FCFA/hr for humans to 347 FCFA for donkeys to 339 FCFA for oxen while increasing costs of human labor at planting time. This is consistent with farmers' perceptions that planting and first weeding are the most labor constraining activities on the farm with the

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[13] Ford (1982) reports a wage rate of 175-300 CFA/day. McIntire reports the following wage rates: Hounde: 250 CFA/day for weeding of cereals; Kougny: 250-300 CFA/day for land preparation, weeding, and ridging; Dori: 500-600 CFA/day for weeding; and Djibo: 350-500 CFA/8 hours for first weeding and 300-500 CFA/day for land preparation.

planting constraint becoming more critical with adoption of animal traction.[14]

The opportunity cost of animal traction units are again difficult to interpret since markets at the critical first weeding periods are not well-defined. The shadow price of 566 FCFA/hr. for donkey and 1251 FCFA/hr. for oxen (for period 5) however, are greater than the market rates of 1000-2000 FCFA/day observed by McIntire (1982).

- Manure: The shadow prices for manure of 2208 FCFA/ton in the donkey solution and 2364 FCFA/ton in the oxen solution compare well with the 1900 FCFA/ton estimated by ICRISAT (1980) (using a production function approach) and 2000 FCFA/ton estimated by Delgado (1978).
- Land: The absence of a land market and the synthetic divisions of land employed in the model make the validation of land prices difficult. However, the relative magnitudes of the shadow prices -- 31,273 FCFA for compound land, 25,232 FCFA for red sorghum land, and 7,879 FCFA for white sorghum land -- are consistent with empirical evidence on land quality differences (Appendix 2) and farmers subjective evaluation of land types.
- Animal units: The shadow prices associated with animal traction units are not particularly meaningful. First, the model covers only

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[14] Results for the village of Diapangou in the relatively more land abundant eastern region indicate that 11 percent and 66 percent of pre-adoptors of animal traction felt that planting and first weeding, respectively, were the most constraining activities. After adopting animal traction, 38 percent and 49 percent of adopters felt planting and first weeding, respectively were the critical constraints. Results for the village of Nedogo in the more highly populated Central Plateau are less clear. The response there was that a majority of farmers felt that labor was not constraining following animal traction adoption suggesting that land constraints were becoming the more critical factor (Jaeger, 1983).

wet season activities and does not incorporate labor costs of caring for animals during the dry season. They reflect the additional amount the farmer should be willing to pay to purchase an additional team. But, considering the small size of farms and lumpiness of the capital input, the shadow price will likely fall sharply with an additional unit purchased.

Productivity per worker: Table 6 presents summary statistics on production per worker of various crops predicted by the farm model compared with Jaeger's (1983) results. The base solution tends to underestimate the magnitude of cereals production but that is mainly a function of yields and resource levels assumed in the model. Animal traction increases the productivity of workers, consistent with Jaeger's results.

The farm model predicts the farmer's resource allocation and cropping strategies reasonably well. It appears to capture the effects of animal traction technology and generates opportunity costs broadly consistent with empirical observation. The next question is how new technology impacts on the farming system.

New Technology Evaluation

One of the promising new agricultural technologies being considered in Burkina Faso is tied ridging. Tied ridging involves the construction of mounds of dirt between ridges in the field, at distances of every several meters or so, to trap rainfall.[15] The technology reduces soil erosion,

[15] The construction of tied ridges can vary considerably from small depressions dug in the ground, which require little labor, to tall ridges formed in a "lattice" type manner which can require considerable labor to construct.

Table 6. Production Per Worker Compared with Observed Results from the Village of Nedogo, 1982.

	Base Model Solution			Jaeger, 1983	
	Hand	Donkey	Oxen	Hand	Donkey
Millet	156	208	285	191	263
White Sorghum	59	48	22	83	72
Red Sorghum	57	7	---	58	50
Maize	25	72	95	15	24
Groundnut	1	14	53	17	24
Bambara Nut			---	9	2
Cowpea	27	16	20	8	8

promotes water infiltration, thereby increasing available soil moisture. The yield response of cereals to a more ample supply of water has been shown to be significant, but constrained by low levels of soil fertility on the Mossi Plateau. However, when tied-ridging is combined with improvements in soil fertility, dramatic increases in cereals yields are possible (Appendix 6). A doubling in sorghum yields has been reported in on-farm trials, highlighting the technology's potential. The question is whether sufficient economic incentives exist for farmers to adopt the new technology.

The partial budget approach to technology evaluation was presented earlier in the paper. An application of the approach to evaluation of several tied-ridging experiments are presented in Table 7. Returns per unit of land and labor of the tied ridging plus fertilizer technology exceed all other technologies tested. The implication, based on these results alone, is that the farmer should shift his resources from traditional white sorghum into white sorghum grown on tied ridges with fertilizer. As pointed out earlier, however, crop budgets do not incorporate competing demands of alternative crop technologies for scarce factors (the critical factor here is labor). The justification for whole farm modelling is to take these relationships into account.

The farm model developed in this analysis is expanded to include the new tied ridging plus fertilizer technology. The objective is to assess the technology's economic viability and impact on the farming system. The procedure for incorporating the new technology in the model along with a synthesis of tied-ridging research in Burkina Faso are given in Appendix 6. The procedure involves expanding the number of activities in the model where an activity includes prices, resource requirements and yield characteristics of the tied ridging technology. Several additional rows are added to account for modern input requirements and resource constraints.

Table 7. Results of Tied Ridging Experiments on Sorghum Fields, Nedogo, Upper Volta, 1983.

Donkey Traction Technology

	I	II	III	IV
Mean Yields (Kg/Ha.)	444	624	604	962
Revenue (CFA/Ha.)	28,860	40,560	39,260	62,530
Cash Inputs:				
100 Kg. Cotton Fertilizer			6,200	6,200
50 Kg. Urea			3,000	3,000
Labor Input (hrs.):				
Base	330	330	330	330
Fertilizer			20	20
Tied Ridges		120		120
Animal and Equipment Depreciation, Maint., & Feed (CFA/Ha.)	3,000	4,000	3,000	4,000
Net Revenue/Ha.	25,860	36,560	27,060	49,330
Net Cash Revenue Minus Labor @ 50 CFA/Hr.	9,360	14,060	9,560	25,830
Revenue/Hr.	78.4	81.2	77.3	105.0

Source: 1983 Purdue SAFGRAD/FSU Field Trial Results, Upper Volta, 1983.

I = Traditional
II = Tied Ridges Made 30 Days After Seeding
III = 100 Kg/Ha. Cotton Fertilizer + 50 Kg/Ha. Urea
IIII = Tied Ridges + 100 Kg/Ha. Cotton Fertilizer + 50 Kg/Ha. Urea

Suppose a new technology involving donkey traction and fertilization is to be introduced in the model. Let X^f_{jl} define the area of crop enterprise "j" on land type "l" cultivated with the new technology. Further, let the terms A^{mf}_{ij} and A^{df}_{ij} represent the technology's requirements for human and donkey labor in period 'i'. Yields of commodity 'k' associated with the new technology are represented by the term, Y^f_{jk}, k = 1, ..., S. Equations (2) through (8), representing the firm's production function (traditional management) can be modified in the manner:

(9) $\sum_j X^m_{jl} + \sum_j X^d_{jl} + \sum X^o_{jl} + X^f_{jl} \leq T_l + e_l * MNR$

(10) $\sum_j A^m_{ij} X^m_j + \sum_j A^{md}_{ij} X^d_j + \sum A^{mo}_{ij} X^o_j + A^{mf}_{ij} X^f_j \leq$

$MHR_i * MA + FHR_i * FA + h^d_i * DK + h^o_i * OX$

(11) $\sum_j A^d_{ij} X^d_{ij} + A^{df}_{ij} X^f_{ij} \leq DHR_i * DK$

(12) $\sum Q_k - \sum_j \sum_k (Y^m_{jk} X^m_j + Y^d_{jk} X^d_j + Y^o_{jk} X^o_j) + Y^f_{jk} X^f_j \leq 0$

(13) $FERT - W_d X^f_j \leq 0$

(j = 1, ..., 27, l = 1, ..., 4, i = 1, ..., 10, k = 1, ..., 5)

Substitution possibilities between the "new" and traditional technologies are defined for land type 'l' in equation (9); human labor (period 'i') in equation (10); donkey labor (period 'i') in equation (11); and yields in equation (12). Labor augmenting or reducing effects are incorporated through the terms A^{mf}_{ij} for humans and A^{df}_{ij} for donkeys. Yield effects of the new technology are introduced through the term, Y^f_{jk}. Equation (13) is an identity relating the demand for fertilizer, FERT, to the fertilizer application rate, W_d, and area, X_j^f.

For purposes of this analysis, let us define a new tied ridging technology in the following way:

- the technology consists of tied-ridging plus fertilizer cultivated on white sorghum land using donkey traction;
- 100 kg/ha of a compound fertilizer (14-25-15 NPK) and 50 kg/ha of urea are applied after planting but before the critical first weeding period. An additional 5 hours of labor are required per hectare to apply the fertilizer;
- the construction of ridges is done at the time of first weeding using donkey tillage equipment. This ridging work is done regardless of whether tied-ridging is done, since ridging is already performed in the "base" donkey traction model. No additional labor is required to perform this activity.
- the "tieing" of ridges is done in the first relatively slack period following the peak labor constraints of first weeding on cereals. This occurs approximately 35-40 days after planting.[16] The tieing of ridges is done entirely by hand though estimates of labor requirements to perform the operation vary tremendously in the literature. For purposes of this study, additional labor requirements of 75, 100, 125, 150, and 175 hours/hectare are utilized to assess the sensitivity of model solutions to various labor inputs.

[16] This is the time that farmers in SAFGRAD/FSU survey villages did the tied ridging. Performing the operation at this time circumvents the high opportunity costs of labor of the critical first weeding labor bottleneck period.

- the expected yield associated with the new technology is 850 kg/ha compared to that of 493 kg/ha assumed in the traditional donkey traction model. The technology is also evaluated at yield levels of 650, 750, and 950 kg/ha to evaluate the sensitivity of model solutions to more pessimistic and optimistic yield scenarios.
- urea and compound fertilizer are costed at 60 and 62 CFA/kg, respectively. These are financial prices paid by farmers, subsidized by the government at a rate of 40 percent. The government of Burkina Faso is in the process of lowering these subsidies to bring domestic fertilizer prices more in line with international prices. After removing the subsidies, urea and compound fertilizer are expected to cost 100 and 104 CFA/kg, respectively.

The variables critical to model outcome are yields, amount of time required to do the tied ridging work and the input prices used to cost fertilizer inputs. Model solutions to alternative values of these three variables are presented in Appendix 7. Several points are apparent in the solution results. First, the new technology always enters the farm plan, although the amount grown can be small (as small as .17 hectares). Only at a yield of 625 kg/hectare or below will the technology not enter solution (even at the lowest labor input). This yield is far below the farm level test results of approximately 850 kg./ha. for tied ridges and low fertilization. Second, the new technology never completely displaces white sorghum cultivated under traditional management practices except when labor requirement are low (see Table 7). At labor inputs of 100 hours/hectare or more to tie the ridges, the model selects to use both the traditional and new white sorghum technologies.[17] In partial budgeting analysis there is no way to define an optimum mix of new and traditional activities as is done above.

Figure 2 illustrates the relationship between alternative yield assumptions, additional labor time spent on tied ridging and total net income of the farm. At yields of 650 and 750 kg/hectare, the new technology is not generating a level of total net farm income that is greatly superior to the traditional donkey traction solution.[18] Substantial improvements are apparent at higher yields, but returns drop rapidly as labor requirements for the tied ridging increase. While the technology appears to have considerable potential, its economic viability depends crucially on what yield and labor input levels are assumed.

The impact of the new technology on the farming system also depends on the price of fertilizer (see Table 9). At the current government subsidized price of 60 CFA/kg for urea and 62 CFA/kg for compound fertilizer, 0.64 hectares of the new technology are employed. At unsubsidized prices, however, the area in new technology falls to .29 hectares while a dramatic decline in white sorghum production takes place.

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[17] The reason for this is the following. With low area under the new technology, the opportunity cost of labor is low (prior to the introduction of the new technology, slack labor with an opportunity cost of 0 existed in labor period 7). The higher returns associated with the new technology provide incentive to expand its hectarage. However, as its area expands, labor becomes constraining and the opportunity cost of labor and the wage bill of the new technology increase. The incentive then is to shift some labor away to the less labor intensive technology -- white sorghum under traditional management -- thereby balancing labor flows between the two technologies. Only at higher yields and lower labor requirements are returns sufficient for the new technology to dominate entirely.

[18] Several factors contribute to this. One is the low level of returns associated with these yield levels. Second, the area of white sorghum land is constrained to be .8 hectares or approximately 12 percent of total area. Increases in total net farm income are constrained by the limited amount of white sorghum land available.

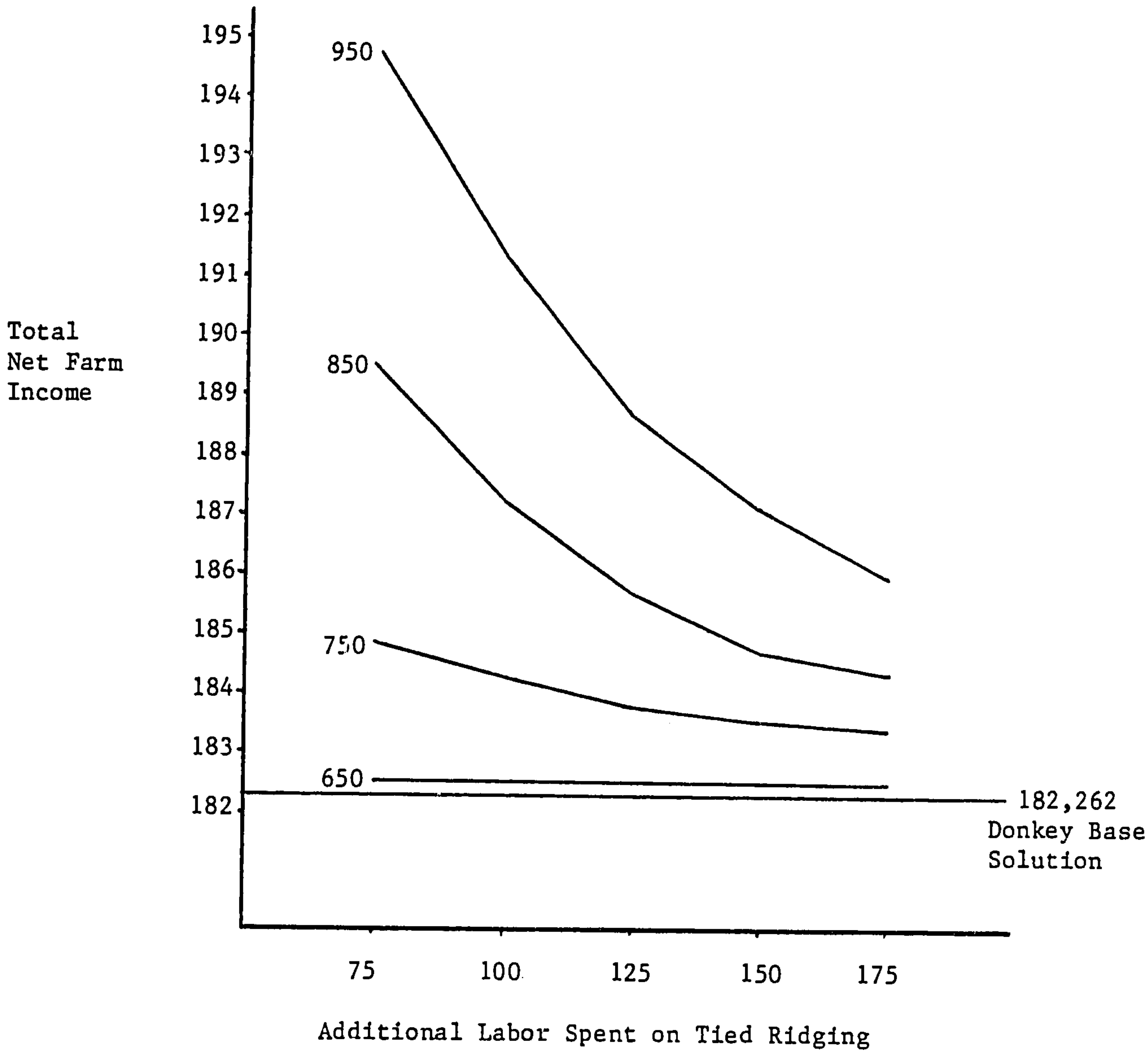

Figure 2: Effect of Various Yields and Time Spent Tied Ridging on Net Revenue of the Farm Using the Subsidized Price of Fertilizer

Table 8. Hectarage of Two Alternative White Sorghum Technologies Given Alternative Labor Assumptions for the New Technology[a]

Technology / Hours Spent on Preparing Tied Ridges	75	100	125	150	175
Area:					
White Sorghum - Traditional	---	.16	.29	.55	.63
White Sorghum - With Tied Ridges	.80	.64	.51	.25	.17
Total Production - White Sorghum	680	622	574	475	446

[a] Evaluated at a yield of 850 kg/ha and the Subsidized Fertilizer Price levels.

Table 9. Technology Evaluated at Subsidized and Unsubsidized Fertilizer Runs

	Without New Technology	With New Technology[a]	
	Base Solution	Subsidized Fertilizer Prices	Unsubsidized Fertilizer Prices
Area (hectares):			
White Sorghum - Traditional	.80	.16	.51
White Sorghum - With Tied Ridges	---	.64	.29
Production (kilograms):			
White Sorghum	384	622	492
Red Sorghum	58	72	57
Millet	1664	1661	1667
Maize	573	557	574
Peanuts	110	237	118
Cowpeas	132	80	124
Total			

[a] Evaluated at a yield of 850 kg/ha and labor for tied ridging at 100 hrs/hectare.

A number of implications can be drawn from the analysis. First, a large increase in yields is needed for the technology to have a significant impact on the farming system but this large yield increase has been obtained in farm trials. There may be a problem of yield variation between years; however, providing a more assured water supply should reduce yield variance. The sensitivity of the model solution to assumptions about labor requirements suggests that more information needs to be obtained for both the timing and quantity of labor used in tied ridging operations. Third, the economic viability of the new technology depends heavily on the price of fertilizer.

The income increase from tied ridges and fertilization on farms with donkey power was only 1 to 4 percent since the tied ridges were considered only for the white sorghum land (representing 12 percent of the total area in crops). Eliminating the present subsidy on fertilizer largely eliminates the return on tied ridges. However, the fertilization levels utilized in the farm trials are still low. Moving up the response curve to higher levels of fertilization is expected to result in higher returns once more water is available.

The farm model proved to be a suitable framework for integrating household survey data with agronomic information from experimental trials. The analysis helped identify key variables affecting economic returns of the technology. Further, it enabled a whole-farm evaluation of the technology's performance emphasizing areas where further empirical research would be desireable. The analysis sets the groundwork for a more comprehensive analysis of the tied ridging technology. An extension of the tied ridges onto other land types at higher fertilizer levels and other modes of application (to reduce labor costs) are areas where further research are required.

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APPENDICES

APPENDIX 1

MARKET PRICES

Table A1.1: Commodity Prices

Commodity	Price (CFA/kg)
White sorghum	59
Red sorghum	55
Millet	58
Maize	60
Cowpeas	92
Peanuts	117

Table A1.2a. Derivation of Annualized Cost of a Fully Equipped Donkey Team, All Regions, Burkina Faso. 1/

Variable	Estimated 1980 Price (FCFA)	Estimated Working Life (Years)	Salvage Value (FCFA)	Annualized Costs (FCFA)
Donkey Purchase Price a/	25,000	7	4,000	5,650
Donkey Drawn Implements: c/				
Plow	14,500	10	1,500	2,815
Weeder	22,000	8	2,000	4,755
Accessories	6,600	5	300	1,925
Equipment Repair (10%) e/				4,310
Grain, Forage, Salt, Medicine f/				2,500
Expected Loss of: g/				
Animals (3%)				750
Equipment (5%)				1,295
Annual Cost of a Donkey Team, γ d/				24,000

Table A1.2b. Derivation of Annualized Costs of a Fully Equipped Oxen Team, Burkina Faso. 1/

Variable	Estimated 1980 Price (FCFA)	Estimated Working Life (Years)	Salvage Value (FCFA)	Annualized Costs (FCFA)
Oxen (2) Purchase Price b/	45,000 * 2	4	90,000 * 2	(4,525)
Oxen Drawn Implements: d/				
Plow	25,000	10	2,500	4,860
Weeder	26,000	8	2,750	5,595
Ridger	8,500	5	425	2,475
Accessories	9,500	5	475	2,765
Equipment Repair (10%) e/				6,900
Grain, Forage, Salt, Medicine (2 oxen) f/				9,000
Expected Loss of: g/				
Animals (3%)				4,500
Equipment (5%)				3,450
Annual Cost of a Oxen Team, γ^o				35,020

Table A1.2a & A1.2b (continued)

[1] Annualized costs of animals and equipment are computed with the Capital Recovery Factor:

$$A = PV \left[\frac{r}{1 - \frac{1}{(1+r)^t}} \right]$$

where: A = annualized cost of the capital item,
PV = present value of capital item defined as purchase price, PP, minus present worth of its future salvage value, SV. That is,

$$PV = PP - SV\left[\frac{1}{(1+r)^t}\right];$$

r = 0.15 discount rate,
t = estimated working life.

[a] The purchase price of a donkey was reported as 30,000 FCFA by the Centre Ouest ORD (1980/81 Annual Report) and 35,000 FCFA by the Centre Nord (1980/81 Annual Report). For the eastern region of the country, estimates range from 18,000 FCFA by Barrett, et al. (1982) in their 1978 eastern ORD study to 20,000 FCFA by Swanson (1981 SAFGRAD-FSU Annual Report) in the village of Diapangou near Fada N'Gourma.

[b] The cost of a pair of oxen in 1980 was reported as 35,000 FCFA by the Centre Ouest ORD (1980 Annual Report) and 45,000 FCFA by the Centre Nord ORD (1980 Annual Report). These costs were the average price of an ox purchased with CNCA credit. Cohen (1982) reports that an ox can be bought for 40,000 FCFA and resold after four years for 55,000 FCFA. The fact that an oxen's resale price is higher than its purchase price has been documented as well by Jaeger (1983) (50,000 FCFA purchase price versus 100,000 FCFA resale value) and by Barrett, et al. (1982) (35,000 FCFA purchase price versus 75,000 FCFA resale value).

[c] The HV2A is a 6" moldboard plow suited for donkeys. It comes complete with a three-tined cultivator but no ridger. Its cost was reported as 27,650 FCFA by the Centre Ouest ORD (1979/80 Annual Report) and 35,500 FCFA by Swanson (1981) in the eastern region. Barrett, et al. placed just the cost of a plow at 11,320 FCFA in 1978. Estimates of the price of a Houe Manga - flexible tined weeder with scarifying equipment (3 tines) - varies from 20,100 FCFA by the Centre Ouest ORD (1980 Annual Report) to 26,050 and 28,500 FCFA by Swanson (1981) for the Centre Est and Est ORD's, respectively. Barrett, et al. report the cost of a weeder as 17,200 FCFA in 1978 with an additional 5,185 FCFA required for accessories.

Table Al.2a & Al.2b (continued)

[d] An HV2B is a multi-cultivator for oxen. It is based on a nine-inch plow with a steel beam. Additional attachments include a chisel point to help break hardened soils, a cultivator with 5 flexible tines plus scarifying and weeding shares. The Centre Ouest ORD (1979 Annual Report) listed the price of an HV2B in 1979/80 as 41,815 FCFA. They also give the price of BM2M plow for oxen as 27,000 FCFA. Barrett, et al. (1982) list the price of a plow as 18,250 FCFA in 1978 and the price of a ridger as 6,470 FCFA. With regards to just weeding equipment, the Centre Nord ORD lists the price of an oxen weeder as 27,960 FCFA. Barrett, et al. report the price of a 5 chisel weeder as 19,635 FCFA and accessories as 7,225 FCFA.

[e] Sargent, et al. (1981, p. 39) estimate repair and maintenance of equipment at 10 percent of purchase price per year. Barrett, et al. (1982, p. 51) observed farmers spending 1264 FCFA per year on average. These latter estimates are probably low, since a large proportion of farmers recently purchased equipment, hence repair costs were lower. Also, farmers were not fully equipped.

[f] Barrett, et al. (1982, p. 38) report the average annual cash expense of maintaining a donkey or ox as 938 or 1,900 FCFA, respectively in 1978. Jaeger (1983) reports expenses of 4,310 FCFA to cover feed grain, salt, etc. for donkeys and 4,138 for oxen. Since oxen require higher levels of feed supplements than donkeys, higher costs are assumed.

[g] Barrett, et al. (1982) in their eastern region farm management study, observed a 1.2 and 5 percent mortality rate per annum of donkey and oxen. The rates 3 percent (750 FCFA per annum) and 5 percent (2250 FCFA) for donkeys and oxen assumed here are similar to insurance rates charged by the Eastern ORD to insure animals in credit schemes (Barrett, et al, 1982, p. 43). For equipment, a figure of 5 percent of purchase price is assumed to cover thefts, irrepairable damage, etc. Labor costs to care for animals are captured through labor demands and opportunity costs of labor calculated within regional supply models. Labor costs during the off-season are assumed to be zero due to lack of alternative sources of employment.

APPENDIX 2

LAND AND DEMOGRAPHICS

Farm Size and Demographics

Table A2.1 summarizes information on total hectares cultivated, residents per household, and number of active workers from various on-farm studies performed on the Mossi Plateau. In studies of mainly hand tillage households, estimates of farm size range from 2.9 to 7.8 hectares. Estimates of total residents per household range from 7.1 to 14.1 persons and active workers 4.4 to 6.6 persons.

The area farmed by AT households appears to be larger than hand tillage households reflecting perhaps the area expansion effects of animal traction. Estimates of farm size of households possessing donkey traction ranges from 5.8 to 8.2 hectares. Residents per household average around 13.5-13.9 persons and active workers 6.4 to 6.6 persons. Data for oxen households is very limited, reflecting the low incidence of oxen traction on the Mossi Plateau.[1] For purposes of this research, figures in Table A2.2 are used as benchmarks for area cultivated, farm size, and number of workers.

Land Quality Differences

The household's endowment of higher quality land is a constraint to the production process. SAFGRAD-FSU (1982) reports that land quality is a dominant factor in farmers' cropping decisions.[2] Personal interviews with farmers showed that land quality is always the basic consideration for determining cropped area. Maize is planted only on the fields surrounding

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[1] Census statistics taken by the Centre ORD show 1,843 pairs of oxen, 1740 single oxen units, 974 horse units and 14,315 donkey units in active use (Ministere du Developpment Rural, ORD du Centre, 1982).

[2] Factors such as risk and labor availability are important as well, but land quality was the factor given most repeatedly by farmers as the major determinant of cropping decisions.

Table A2.1: Estimates of Total Area Cultivated, Total Residents and Active Workers per Household Taken from Various Studies Performed in Burkina Faso

Study	Total Hectares	Residents/ Household	Active Workers
		Hand Tillage	
Jaeger, 1983			
- Nedogo	4.41		4.71
- Diapangou	5.03		4.36
Kabore, Lebene, Matlon, 1983			
- Kolbila	5.6	14.1	
- Ouonon	2.9	7.1	
Swanson, 1982			
- Nedogo	7.79	12	5.9
- Digre	5.06	10	6.5
		Donkey Tillage	
Jaeger, 1983			
- Nedogo	8.18		6.64
- Diapangou	7.45		6.38
Kabore, Lebene, Matlon, 1983			
- Kolbila	5.8	13.5	
- Ouonon	6.0	13.9	

Table A2.2: Land and Demographic Assumptions, Representative Hand Tillage and Animal Traction Households

	Hand Tillage	Donkey Tillage	Oxen Tillage
Total hectares cultivated	4.5	7.8	9.0
Total residents/household	11	13	14
Active workers/household	6.0	7.5	8.0
Males	2.0		
Females	4.0		

the household living areas where night-soil and animal manure are deposited. Rice is planted only on bottom land. Sorghums are reserved for areas of higher soil fertility (land recently taken out of fallow or manured land), while millet is normally planted on the less fertile land.[1] Red sorghum is normally planted on soils higher in fertility than white sorghum (see Cohen, 1982). It is commonly planted on highly manured compound land or land recently taken out of fallow. Cowpeas are almost always planted in association with sorghum and millet because of their vulnerability to serious insect infestation if planted as a sole crop.

ICRISAT (1980) outlines six soil types that farmers consider when making their crop allocation decisions: a) soils high in organic matter adjacent to the compound; b) lowland soils, periodically inundated; c) soils with higher loam or clay fractions located in the bush and those recently taken out of fallow; d) loamy-sand soils adjacent to the compound or village but low in organic matter; e) loamy-sand soils located at some distance in the bush but low in organic matter; and f) shallow, gravelly-sand soils, irrespective of location. Under a scenario of "normal arrival of rains"[2]

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[1] White sorghum is highly valued by farmers because it reportedly can be stored twice as long as millet (i.e., 3 to 4 years compared to 1 to 2 years for millet). It also yields better than millet under desirable soil and rainfall conditions. On the other hand, white sorghum requires better land, more consistent rainfall and is less disease and striga resistant than millet. While millet is lower yielding, it is more drought and disease resistant. Farmers say that, even in the worst of years, some millet can always be harvested.

[2] Normal arrival of rains denotes early or average arrival of rains and good distribution during the planting period. Cropping patterns are reportedly adhered to in the case where the onset of rains is moderately delayed. However, with extremely late arrival of rains lowland soils would normally be left unplanted, plantings would consist almost exclusively of millet intercropped with cowpeas with gravelly soils normally left idle (ICRISAT, 1980).

farmers would plant maize on soil type "a"; red sorghum on soil types "b" and "c" (in particular red or white sorghum often intercropped with cowpeas are cultivated on soils recently taken out of fallow); millet and/or sorghums, often mixed with cowpeas, on soil type "d"; millet, often intercropped with cowpeas on soil type "e"; and millet as a sole crop on soil type "f".

To the authors' knowledge, there are no empirical measurements of land quality differences that would permit direct formulation of land quality constraints. An indirect approach was taken. First, four types of land were incorporated in the model based on farmer responses concerning cropping decisions:

1) Compound Land - land that lies adjacent to the family's compound and receives large deposits of night soil, wastes, and animal manure. The soil has a high organic matter content and high fertility.
2) Red Sorghum Land - consists of land just taken out of fallow, low-lying soils, soils with high loam fractions and/or soils receiving large deposits of animal manure. Soils are high in organic matter and fertile, but less so than "compound" soils.
3) White Sorghum Land - consists of loamy sand soils adjacent to the compound and/or village that are lower in organic matter. The soils receive minor deposits of manure and while inferior to red sorghum land it is superior to the lower quality fields where millet is grown.
4) Low Fertility Bush Fields - loamy sand soils, located in the bush and shallower more gravelly-sand soils. Soils receive no application of manure, are low in organic matter and have been continuously cultivated for several years. This is the most abundant type of land but also the lowest in fertility.

Having defined soil types, endowments of each type of soil are calculated from data on cropping patterns and farm size. Data in Table A2.3 show the percentage of crops cultivated on AT and non-AT households in two regions of the Mossi Plateau.

Table A2.3: Cropping Patterns Observed by Various Studies on the Mossi Plateau

Crop	Nedogo: Hand Tillage	Nedogo: Donkey Tillage	Nakomtenga and Nabitenga: Hand Tillage	Nakomtenga and Nabitenga: AT Tillage
	(percentage)			
Red Sorghum	12.7	8.6	13.1	8.6
White Sorghum	15.4	18.5	6.4	8.6
Millet	62.0	63.0	73.3	73.5
Maize	2.0	2.4	2.0	1.8
Rice	0.5	0.1		
Groundnuts	5.4	5.5	4.4	6.0
Bambara Nuts	1.8	1.2	0.8	1.5
Total Land (hectares)	4.41	8.18	2.51[a]	3.36[a]
Active Workers	4.71	6.64		

[a] Area represents fields of the household head. It excludes private fields, hence underestimates total area by perhaps 15% (McIntire, 1981).

Source: Information for Nedogo were taken from Jaeger (1983). Information for the villages of Nakomtenga and Nabitenga were taken from McIntire (July, 1981).

Based on the above table and preceding information on crop allocation by land type, endowments of land supply are estimated in Table A2.4.

The above table was computed in the following manner. Since maize and some red sorghum are grown on compound land and maize represents roughly 2 percent of total area cultivated, then the endowment of compound land is .16 hectares (i.e. 3.5 percent of 4.5 hectares). Based on similar calculations for red and white sorghum, the area of red sorghum land is .55 hectares and white sorghum land is .80 hectares. Since labor, not land, is the principle

Table A2.4: Estimates of Land Endowments.

Type of Land	Crops Primarily Grown	Land Availability (hectares)
Compound land	Maize, red sorghum	.16
Red sorghum land	Red sorghum, maize, white sorghum	.55
White sorghum land	White sorghum, millet	.80
Poorest quality bush land	Millet, peanuts	unbounded
Total Area Cultivated		4.5[a]

[a] Estimates of total area cultivated per household are 5.6 and 2.9 hectares respectively for the villages of Kolbila and Ouonon near Yako (Kabore, Lebene, and Matlon, 1983); 4.41 for Nedogo (Jaeger, 1983), and 2.51 for the combined villages of Nakomtenga and Nabitenga (McIntire, July 1981).

Note: Total area cultivated from Table A2.2.

constraint to expanded millet cultivation, the area of bush land endowment is left unconstrained.[3] These figures represent land resource availabilities and are included as right hand side coefficients of the land quality constraints in the farm model.

[3] The assumption that the area of millet land is not constraining is supported by two arguments. First, farmers responses to SAFGRAD-FSU (1983) surveys were that labor, not land was the factor constraining expansion of millet area. Second, the adoption of animal traction (a labor-saving technology) appears to be positively correlated with farm size. This may be brought about by the need for larger labor supply to permit animal traction adoption.

APPENDIX 3

LABOR

Demand for Labor: Seasonal Labor Flows, Hand Tillage Household

Perhaps the most important determinant of agricultural production in subsistence farming systems is household labor and its allocation among alternative crop enterprises. For a given crop technology, a timely flow of labor is required to achieve expected yields under "normal" conditions. If an operation such as weeding is poorly performed or delayed, yield reductions occur. Furthermore, labor-saving technologies such as animal tractic may reduce labor requirements per unit of area and/or improve the timeliness of operations. This can lead to area expansion and/or yield augmenting effects (see Appendix 5 for animal traction performance). In this section, the labor coefficients for hand tillage technologies are derived. The labor adjustments that accompany animal traction adoption are considered in Appendix 5.

A number of studies have been done in West Africa using linear programming techniques to model household production activities. (See Balcet and Candler, (1981) and Crawford (1980) for Nigeria; Delgado (1978) for Burkina Faso; Niang (1980) for Mali; Niang (1980), and Haswell (1953) for Senegal). The formulations vary across studies, but several common features exist: 1) Labor flows are treated in considerable detail; Delgado, for example, divides annual labor flows into fortnightly periods -- 26 in total -- which provide the base for formulating labor constraints. 2) Labor plays a very significant role in the modelling outcome; the LP tableau is largely comprised of labor coefficients, hence labor tends to "drive" technical substitution in the model. Based on the experience of these studies along with farming systems research performed in Burkina Faso, consideration was given to the following in model formulation:

1) Critical labor "bottlenecks" are reported first and foremost at first weeding and to a lesser degree at planting (Jaeger, 1983). Labor is not normally constraining at time of second weeding or harvesting.

2) Given that first weeding is the major "bottleneck" period, emphasis is given to capturing labor trade-offs at this time. A period of even a fortnight can smooth out peak labor demands and diminish the effect of seasonality.

For the model, total labor covers only planting, tilling, first weeding, and some second weeding activities. This duration is sufficient to capture the key labor constraints affecting production, but may not capture marketing constraints in the off-season (i.e., for peanuts; see Crawford, 1980) that may influence cropping decisions. Labor constraints during the critical first weeding period are based on weekly time periods rather than a fortnightly labor period.[2]

To determine labor coefficients in the model, information is required on the amount of labor input by time period by crop by type of technology used. Labor budgets are available in the literature which express labor input per hectare of various crops by total hours worked and/or in some

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[1] The motivation for limiting labor constraints to the planting through first weeding period stemmed from the necessity to keep the problem small enough to run on a micro-computer. The delineation of total labor into weekly time periods at first weeding plus incorporation of constraints to account for donkey and oxen traction technologies, required labor constraints for other periods to be excluded. While including time constraints corresponding to other wet season and dry season activities would be desirable, it was felt that providing more disaggregation of critical labor periods was a preferable approach.

[2] The problem with using weekly periods is whether data are sufficiently rich to permit this level of disaggregation.

cases by type of activity, but data on the seasonal distribution of labor is less abundant. Crop calendars suitable for defining seasonal labor flows are not readily available. This subject will be returned to shortly.

Labor times reported by various studies for the Central Mossi Plateau are presented in Table A3.1. Labor is disaggregated by crop, task and type of technology used. The comparison of labor times across studies is a difficult procedure. First, certain studies like SAFGRAD-FSU use productivity weights to adjust for perceived age-sex differences among workers in the household. Women and children are generally considered less productive than a male, hence their estimates of male-equivalent hours underestimate actual hours worked. Second, a distinction is not always made between animal traction (AT) and non-AT households. The labor times reported are for a mixed sample representing some weighted average of the two. Third, obvious differences exist in methodologies used to collect and measure labor times (i.e., different ways that household versus private fields are treated; what activities are covered; whether travelling time to and from fields are included).

A number of adjustments have been made to the data in A3.1 to place them on a common basis for comparison. First, activities are excluded that are done in the dry season prior to the onset of rains and planting activities (mainly land clearing and manure application). Second, harvesting hours, where applicable, are excluded from total hours. Labor times in Table A3.1 then have been standardized to cover labor activities from land preparation/planting through second weeding. Adjustments for man-equivalent hours reported by SAFGRAD-FSU and "unpublished Nedogo" data are not made. To obtain estimates of actual hours worked, figures should be multiplied by a factor of 1.4 (see Annex 3.1).

Table A3.1: Labor Times Reported in Various Studies for Various Crops in Terms of Total Hours Worked and by Type of Activity

Hand Tillage Farms

No.	Study	Type of Activity	Maize	Red Sorghum	White Sorghum	Millet	Peanuts
1	SAFGRAD-FSU, 1983 - Nedogo[1,2]	Planting			73.4[3]	48.1	179.7
		First Weeding			239.7	165.1	233.8
		Second Weeding			158.1	97.3	
		Total			471.1	310.5	413.6
2	Singh, et al, 1983	Land Prep.	218		27[3]	24	136
		Planting	88		89	68	83
		First Weeding	259		285	237	307
		Second Weeding	140		187	162	4
		Total	705		588	491	530
3	Swanson, 1982 - Digre[4]	Land Prep.					183
		Planting				35	82
		First Weeding				135	180
		Second Weeding				94	
		Total				264	445
4	Swanson, 1982 - Nedogo[5]	Total	1167		467	454	
	Unpublished Statistics 1982 - Nedogo[2,6]	Land Prep.	189	15	10	11	170
		Planting	112	99	80	51	185
		First Weeding	181	169	161	115	213
		Second Weeding	37	87	183	70	
		Total	519	370	434	247	568

Table A3.1: (continued)

Hand Tillage Farms

No.	Study	Type of Activity	Maize	Red Sorghum	White Sorghum	Millet	Peanuts
5	ICRISAT, 1980 - Nabatengo and Nakomtenga[1,4]	Land Prep.	225	29	10	7	213
		Planting	127	98	145	78	144
		First Weeding	201	433	484	263	347
		Second Weeding	71	276	302	152	11
		Total	624	836	941	500	715
6	McIntire, July 1981	Land Prep.	175	21	6	22	272
		Planting	134	98	145	79	145
		First Weeding	201	339	558	298	353
		Second Weeding	71	267	313	167	186
		Third Weeding	74				
		Total	655	725	1022	566	956

Table A3.1: (continued)

[1] The sample includes both hand tillage and donkey households though hand tillage households predominate.

[2] Labor times are weighted to account for productivity differences between age-sex and type of traction groups. Labor times are expressed in terms of man-equivalent units and thus underestimate time worked.

[3] Labor times were reported for "sorghum" only. Data are uncluded under white sorghum since it normally is the more significant crop.

[4] Time worked on land clearing, manuring, and harvesting is excluded. Total labor then is time worked from the period of land preparation through second weeding.

[5] Actual hours and yields reported by Swanson were 553 hrs and 494 kg/hectare for millet, 525 hours and 194 kg/ha for white sorghum, and 1233 hours and 598 kg/ha for maize. Hours are adjusted to remove time spent for harvesting using the weights .11 (hours per kg harvested) for maize and .25 for white sorghum and millet. These weights were estimated from yield and harvesting labor data reported in various other studies.

[6] Labor times were computed from a sample of 21 fields for each of the respective crops for the village of Nedogo, 1982. This was the same data used to create the labor calendar shown in Table A3.3.

Since most of the millet and sorghum cultivated is intercropped with cowpeas, hours reported in various studies reflect labor for cereals/cowpea mixtures rather than sole crops. An examination of Table A3.2 suggests that:

1) time worked on millet is the lowest among crops. Several reasons for this are: a) lower soil fertility creates less of a weeding problem; b) millet fields are generally located further from the household resulting in greater travelling time and correspondingly less time spent in the field; c) millet fields are planted later than those of sorghum although field work terminates at roughly the same date in September.

2) total time worked on peanut fields per unit of area is consistently greater than that of millet but less than sorghums and maize.

3) total time worked on maize fields is greater than on sorghums, though the ICRISAT studies appear to refute this.

4) time spent on red sorghum tends to be less than that of white sorghum (note the conclusion is based on few observations).

Table A3.2 outlines the total labor coefficients assumed for hand tillage technologies in the model. The labor coefficients are derived from Table A3.1 based on the following considerations:

a) Since millet is primarily grown on lower quality bush soils, labor times reported for millet in Table A3.1 should be indicative of cereals grown on bush land. Taking the median of hours in Table A3.1, the amount of time worked on millet is estimated at 400 hours/hectare. Since cultural practices of millet and sorghum are similar both are assigned the same total labor requirements.

Table A3.2: Hours Worked Per Hectare Assumed in the Model for Various Crops

	Millet Land	W. Sorghum Land	R. Sorghum Land	Compound Land
Red Sorghum		470	550	700
Red Sorghum/Cowpeas		518	606	
White Sorghum	400	470	550	700
White Sorghum/Cowpeas	445	518	606	
Millet	400	470		
Millet/Cowpeas	445	518		
W. Sorghum/R. Sorghum		470		700
Millet/W. Sorghum	400	470		
Maize		500	575	680
Red Sorghum/Maize				
Groundnuts	530	580		

b) Groundnuts are also assumed to be primarily grown on bush land. Time worked per hectare is roughly 1.3 times greater than millet. The factor 1.3 and weights used below are adapted from median values estimated from Table A3.1.

c) Labor requirements are higher when cereals are inter-cropped with cowpeas. An ICRISAT study (1982, p. G45) shows intercropping cowpeas with cereals increases labor requirements primarily at first weeding and to a lesser degree at second weeding. Using the ICRISAT data and assuming a cowpea planting density of 1000-1500 plants/hectare, it is estimated that planting increases by 4 hours/hectare while first weeding and second weeding labor times increase by 15 and 5 percent, respectively. This increases total labor of cereals on millet land by approximately 40 hours per hectare.

d) Given the median of labor times reported in Table A3.1, around 470 hours are required per hectare of white sorghum. Since white sorghum is primarily grown on higher quality white sorghum land, this figure is the base from which labor times of other crops are estimated. Red sorghum, millet, and various sorghum and millet mixtures are assumed to have the same labor requirements because of their agronomic similarity. Mixtures containing cowpeas are assigned higher labor inputs according to the percentages in (c) above.

e) Crops grown on red sorghum land are assumed to require more labor than crops on white sorghum land due to higher output levels and greater weeding requirements associated with higher soil fertility. However, this hypothesis is not supported by data in Table A3.1. Why this is so is unclear, and lack of information hampers the analysis of causal factors.

f) Total hours for cereals on compound land are based on average labor times reported for maize in Table A3.1 (since maize is the predominant crop grown on such land). Maize is assumed to require less labor than sorghums or millet (on compound land) due to its shorter growing season.

As noted earlier, information for both total labor and scheduling of labor activities are needed to formulate labor constraints in the model. Graphic or descriptive calendars of labor activities can be found in Delgado (1978), Singh, et al. (1983), Ford (1982) and ICRISAT (1980). These (particularly line graphs) assume that labor is performed with equal intensity in all periods in which an activity is performed. For disaggregated labor flows, a calendar showing the percentage of total labor worked by period is needed.

A labor schedule showing the percentage of total labor time (from land preparation through second weeding) spent by period through the agricultural season is provided in Table A3.3. Observations concerning the scheduling of major activities such as land clearing and manuring are assumed to be done prior to the onset of constraint 1, while harvesting, threshing and storage commence after termination of constraint 10. All major labor activities from land preparation through second weeding of major cereals are covered by the 10 labor constraints.

At the beginning of the agricultural season emphasis is given to cultivation of red sorghum and rice fields. Following first weeding of red sorghum, work shifts to tilling white sorghum and then millet. Planting of maize and peanuts is concentrated during the bottleneck period of first weeding of cereals (constraints 4 and 5). Following first weeding of millet, weeding commences anew on red sorghum and maize then on white sorghum, peanuts, and millet in sequence.

Table A3.3: Agricultural Labor Calendar Used in the LP Model (Percent of Total Labor Time by Period).[a]

Constraint	Time Period	Red Sorghum	White Sorghum	Millet	Maize	Peanuts	Rice
1	May 3 - June 6	20.0	18.4	18.4	--	6.6	10.2
2	June 7 - June 13	9.2	3.4	3.8	--	7.1	16.9
3	June 14 - June 20	7.1	10.3	5.5	16.6	8.7	17.4
4	June 21 - June 27	8.8	6.7	5.7	29.8	11.7	8.2
5	June 28 - July 4	4.3	11.5	8.3	11.5	22.0	0.4
6	July 5 - July 11	3.5	1.1	12.0	6.4	1.5	5.4
7	July 12 - July 18	3.4	0.8	11.4	1.4	2.0	10.1
8	July 19 - Aug. 1	16.1	8.8	7.5	27.5	10.9	9.3
9	Aug. 2 - Aug. 22	18.6	30.9	17.5	5.1	25.9	17.7
10	Aug. 23 - Sept. 12	9.0	8.1	10.1	1.7	3.6	4.4

[a] This information was adapted from labor data collected by SAFGRAD-FSU for the village of Nedogo in 1982. Labor data includes only time spent on land preparation, planting, tillage, first weeding, and second weeding activities. A sample of 21 fields,one per farmer, were used to derive the calendar.

Table A3.4: Schedule of Labor Activities For Various Crops Observed in the Village of Nedogo, Upper Volta, 1982.[a]

Constraint Number	Time Period	Observations
1	May 3 - June 6	Planting of red sorghum, white sorghum and millet takes place. Soil preparation and planting of rice begins.
2	June 7 - June 13	First weeding begins on red and white sorghum fields. Soil preparation and planting continues for rice and begins for peanuts.
3	June 14 - June 20	First weeding continues for red and white sorghum and begins for millet. Soil preparation and planting continues for peanuts and rice while first seeding on early planted rice fields begins.
4	June 21 - June 27	First weeding continues on red sorghum, white sorghum, millet, and rice. Soil preparation and planting take place on later fields of peanuts. Land preparation and planting of first maize fields takes place.
5	June 28 - July 4	First weeding of red and white sorghum, millet, and rice. Last planting of peanuts and maize.
6	July 5 - July 11	First weeding continues on red sorghum, white sorghum, millet, and rice fields.
7	July 12 - July 18	First weeding continues on red sorghum, white sorghum, millet, and rice fields.
8	July 19 - August 1	First weeding of millet and major cereals and beginning of second weeding of red and white sorghum and rice. First weeding of peanuts and maize.
9	August 2 - August 22	Second weeding of all major cereals and first weeding of peanuts and maize.
10	Aug. 23 - September 12	Continued second and final weeding of all cereals. First weeding is finished on peanut fields.

[a] The schedule of crop activities was summarized from labor data collected by SAFGRAD-FSU for the village of Nedogo during the 1982/83 crop season. The observations and scheduling of labor operations are derived from labor times computed for land preparation, planting, first weeding, and second weeding activities on a sample of fields for each crop.

Labor (total hours) assumptions in Table A3.2 combined with the labor calendar in Table A3.3 are used to derive labor coefficients by crop and type of land under hand tillage technology. The following assumptions were made:

- Millet, sorghums, and the two crops in "association" planted on millet land are assumed to follow the labor schedule for millet. Groundnuts planted on millet land follows the labor schedule for groundnuts.
- Millet, sorghums, and "associations" planted on white sorghum land follow the labor schedule of white sorghum. Peanuts and maize are assumed to follow the labor schedules of peanuts and maize, respectively.
- Red and white sorghum, and "associations" planted on red sorghum and compound land follow the labor schedule of red sorghum. Maize follows the labor schedule of maize.

Supply of Labor: Stock of Labor Available for Agricultural Activities

To determine the quantity of labor available during the agricultural season, information is needed on the number of workers in the household, amount of time available for work per day, and number of days worked per week. In Appendix 2 (Table A2.2), it was assumed that a hand tillage household consists of 11 residents, including 6 active workers: 2 male adults and 4 female adults.[3] It is further assumed that no opportunity exists to hire outside labor.[4]

The amount of time that workers spend per day on agricultural activities depends on their material goods-leisure utility surface and returns to agricultural and non-agricultural employment. The period when labor activity is most critical is at first weeding time (mid to late June). Jaeger (1983) notes that 70 percent of the farmers in his hand tillage sample (for the village of Nedogo) reported first weeding as the most labor constraining activity; the next most constraining activity is planting (reported by 30 percent of the farmers).

Labor intensity per day also appears to be at its peak during first weeding.[5] Figures adapted from Swanson (1981) show farmers on average work between 5.3 and 5.7 hours/day during the critical weeks of first weeding. Ancey (1974) reported that workers in Yako (in June) worked an average of 4.9 hours per day and 4.5 hours per day at Koudougou.

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[3] Delgado (1978) reports 1.66 male adults, 2.01 female adults, .63 male children and .48 female children on average in Bisa and Mossi households. Age groups are 15-60 for adults and 8-14 for children. Singh, et al. (1983) reports 1.8 and 1.7 male adults, 2.8 and 2.0 female adults, .4 and .2 male children, and .5 and .25 female children for the villages of Nedogo and Digre, respectively. Singh, however, converts labor of females and children into male-adult equivalents using the weights .75 for female adults and .5 for children. Dividing through by these weights results in 3.7 and 2.7 female adults, .8 and .4 male children and 1.0 and .5 female children for the above two villages, respectively. Age groups are 15+ for adults and 10-14 for children.

[4] ICRISAT (1980) reports that non-household workers contributed less than 2 percent of total farm labor time and most of that was contributed at non-critical second weeding. Singh, et al. (1983) reports hired labor contributed 4.1 percent and 2.7 percent (percentages computed from reported data) of total labor on millet and sorghum fields, respectively.

[5] Labor intensity also tends to peak at harvest time but labor is not as physically demanding.

However, the amount of time worked per day varies by sex. Brun, Bleiberg, and Goihman (1981) reported that male farmers on the Mossi Plateau worked an average of 4.7 hours per day (5.3 hours including walking to and from fields) on weeding activities.[6] In a parallel study, Bleiburg, et al. (1980) reported that women work 3.0 hours/day (3.9 hours including walking to and from fields) while performing the same activity.

Given the above information, the quantity of labor available for work on the representative farm can be derived. Earlier it was noted that 2 male workers and 4 female workers were available for work on the farm. Assuming males and females are equally productive in performing various tasks but that women work shorter days,[7] labor intensity is estimated as 6.0 hours for males and 4.5 hours per day for women. It is also assumed that farmers can potentially work 6 days per week or 25 days per month for weeding activities but only 2.8 days/week for planting. Less time is allowed for planting (1st constraint) because rains come infrequently and farmers can plant only 2 or 3 days following a rain (ICRISAT, 1983). The stock of labor available for cropping activities on the farm is computed in Table A3.5.

For purposes of the model, the amount of time available for work per day remains the same in all periods. While this is unrealistic, the end result is that labor will be binding in the critical periods (e.g., first weeding) while slack labor will exist in other periods that can be utilized

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[6] These figures represent an average over all weeding activities performed. Thus they probably underestimate the true intensity of labor during the peak bottleneck period.

[7] Considerable controversy exists over this issue with some studies showing women to be less efficient than males while performing certain activities; others present evidence to the contrary. For a review of this literature see Roth (1979).

Table A3.5 Quantity of Household Labor Available for Crop Production Activities.

Constraint	Time Period	Total Available Days	Workable Days	Total Labor Supply (in hours) [a]
1	May 3 - June 6	35	14	420
2	June 7 - June 13	7	6	180
3	June 14 - June 20	7	6	180
4	June 21 - June 27	7	6	180
5	June 28 - July 4	7	6	180
6	July 5 - July 11	7	6	180
7	July 12 - July 18	7	6	180
8	July 19 - Aug. 1	14	12	360
9	Aug. 2 - Aug. 22	21	18	540
10	Aug. 23 - Sept. 12	21	18	540

[a] Total Labor Supply = (2 Male Adults X workable days X 6.0 hours/day) + (4 female workers X workable days X 4.5 hours/day)

for other activities (i.e., leisure, off-farm employment, etc.). Only 2.8 days are available in period 1 (i.e., time of planting) because planting is possible for only several days following a rain. Thereafter, the soil becomes too hard to work. Fourteen workable days out of a 5 week period suggests that perhaps 5-7 rains come which are suitable for planting.

Annex A1.B: Procedure for Reconverting Weighted (Male-equivalent) Hours Into Actual Hours Worked

The following formula is used to convert actual hours worked into male-equivalent hours (ME):

$$a_i MH_i + b_i FH_i + c_i CH_i = e_i(TH_i)$$

where:

MH_i = male adult hours worked on i^{th} activity

FH_i = female adult hours worked on i^{th} activity

CH_i = children hours worked on i^{th} activity

TH_i = total hours worked on i^{th} activity

a_i = productivity coefficient converting male adult hours to man-equivalent hours for the i^{th} activity (usually normalized at 1)

b_i = productivity coefficient converting female adult hours to man-equivalent hours for the i^{th} activity

c_i = productivity coefficient converting children hours to man-equivalent hours for the i^{th} activity

e_i = ratio of male-equivalent hours to actual hours

Rearranging terms, the average ratio of man-equivalent hours to actual hours can be computed as:

$$e_i = a_i \frac{MH}{TH} + b_i \frac{FH}{TH} + c_i \frac{CH}{TH}$$

The ratio e_i equals the sum of productivity coefficients of respected age-sex groups (a_i, b_i, c_i) multiplied by their respective contributions to total time worked on the farm (MH/TH, FH/TH, and CH/TH). For the village of Nedogo, Swanson (1981) reported male adults contributed 32 percent of total labor time on the farm, female adults contributed 42 percent and children, 26 percent. SAFGRAD-FSU when calculating male-equivalent hours employ the productivity weights: 1.0 male adult equals 1.0 man-equivalents

(ME); 1.0 female adult equals 0.75 ME; and 1.0 child equals .50 ME, irrespective of the labor activity performed. Assuming weights do not vary by type of activity (subscript 'i' dropped), the ratio can be combuted as:

$$e = 1.0(.26) + .075(.42) + .50(.26) = .705$$

An estimate of actual hours worked can be obtained from the formula:

$$1.0\ ME = e*TH$$

$$TH = \left(\frac{1.0}{e}\right) * ME$$

where $(1.0/e) \approx 1.4$.

APPENDIX 4

YIELDS

Yields

Yield data are required for the complete set of crop activities incorporated in the model. For a given type of land (see Appendix 2), yields (i.e., millet/cowpeas) will vary by crop and type of technology employed. Conversely, for a given level of technology (i.e., hand tillage, no modern inputs) crop yields change as land types vary (i.e., as one moves up the scale from lower quality bush fields to higher quality compound fields).

Table A4.1 summarizes yield information taken from a collection of research studies performed in Burkina Faso. The table presents yield levels for various crops under three types of tillage practices (manual, donkey, and oxen tillage). A review of the table points out: 1) yield data are relatively abundant for millet and white sorghum but not for red sorghum, maize and peanuts; 2) observations become scarce for animal traction technologies, especially for oxen traction.[1] Yield effects of new technologies (fertilizer, tied ridging) are reported later in Appendix 6.

Yield assumptions in the farm model are given in Table A4.2. The coefficients were derived from actual yield information obtasined from on-farm studies (Table A4.1), assuming the following:

a) Empirical estimates of yields on soils corresponding to the land-type classification employed in the model are not available. Given that crops are land-quality specific (see Appendix 2), however, a base level of yields can be inferred from crops normally grown there. Based on data in Table A4.1, yield levels of 340 kg/ha for

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[1] One reason for this is that oxen traction on the Mossi Plateau is not as widely used as donkey traction.

Table A4.1: Yields Reported for Various Crops, Selected Studies, Central Mossi Plateau of Upper Volta

	Hand Tillage Farms				
Study	Millet	White Sorghum	Red Sorghum	Maize	Peanuts
SAFGRAD-FSU, 1983	342[a]	410[a]			461[a]
SAFGRAD-FSU, 1984					
- Nedogo	346	430			
- Diapangou		363		1270	
Jaeger, 1983					
- Nedogo	350	515	421	1140	502
- Diapangou	329	171		1429	256
Singh, *et al.*, 1983	352	423		772	484
Swanson, 1982					
- Digre	153				317
- Nedogo	494	194		598	
Kabore, *et al.*, 1983	207	360	521		
ICRISAT, 1981		376			

[a] Represents a village sample average taken across manual and animal traction households.

Table 4.2: Yield Levels for Sole Crops and Crop Mixtures by Type of Land and Traction Technology Assumed in the Farm Model.

Type of Land	Crop Mixture	Hand Tillage	Donkey Tillage	Oxen Tillage
Millet Land	W. Sorghum	310	325	335
	W. Sorghum/Cowpeas	310/35	325/20	335/20
	Millet	340	357	367
	Millet/Cowpeas	340/35	357/20	367/20
	Millet/W. Sorghum	255/78	268/81	275/84
	Peanuts	480	430	430
White Sorghum Land	R. Sorghum	420	470	483
	R. Sorghum/Cowpeas	420/45	470/27	483/27
	W. Sorghum	440	493	506
	W. Sorghum/Cowpeas	440/45	493/27	506/27
	Millet	410	460	472
	Millet/Cowpeas	410/45	460/27	472/27
	W. Sorghum/R. Sorghum	330/105	370/118	380/120
	Millet/W. Sorghum	308/110	345/123	354/127
	Maize	400	468	480
	Peanuts	520	470	470
Red Sorghum Land	R. Sorghum	600	702	720
	R. Sorghum/Cowpeas	600/55	702/35	720/35
	W. Sorghum	550	644	660
	W. Sorghum/Cowpeas	550/55	644/35	660/35
	Maize	650	793	813
Compound Land	R. Sorghum	850	1080	1105
	W. Sorghum	770	978	1000
	R. Sorghum/W. Sorghum	638/185	810/245	829/250
	Maize	1000	1320	1350

millet, 440 kg./ha. for white sorghum, 600 kg./ha. for red sorghum, and 1000 kg./ha. for maize were chosen as norms for respective soil types.

b) Millet production is assumed to have a comparative advantage on what is termed millet land, white sorghum on white sorghum land, red sorghum on red sorghum land, and maize on compound land. Thus, while millet yields increase from 340 kg/ha (on millet land) to 410 kg/ha on white sorghum land, the response is insufficient to replace white sorghum, which yields 440 kg/ha.

c) No positive or negative yield effects are assumed to result from intercropping. That is, intercropping cowpeas with white sorghum does not affect the latter's yield.

d) Animal traction generally has a positive effect on cereal yields but a negative effect on groundnut yields (Appendix 5, Table A5.4). Positive yield effects associated with animal traction adoption are shown in Table A5.2.

e) The low levels of cowpea yields assumed in the model are supported by ICRISAT research which shows yields of 14 kg/ha when intercropped with white sorghum and 9 kg/ha when intercropped with millet (ICRISAT, 1980). It's possible that yields are greatly underestimated due to the manner in which they harvested or how yields are measured.

APPENDIX 5

ANIMAL TRACTION TECHNOLOGY

Animal Traction Technology

Until now the discussion has focused on the representative farm operating with hand tillage technology. This section summarizes research on animal traction on the Mossi Plateau of Upper Volta and describes how its effects are incorporated into the farm model. While a clear concensus on the effects of animal traction does not exist, its adoption has a potential impact in several areas: 1) improved yields may result due to use of animal traction for land plowing and better timeliness of field operations; 2) manure from animals raises soil fertility; and 3) as a labor saving technology it can lead to reductions in human labor (per unit of area) during tillage activities. Each of these effects are discussed more fully below.

Yield Effects

The use of animal traction with tillage activities can potentially increase yields in two ways. First, deep plowing of the soil with animal traction equipment should lead to better incorporation of crop residue and improved water retention. Second, better timeliness of operations associated with the labor saving effects of animal traction should augment yields.[1]

Information on the yield effects associated with use of animal traction is not abundant. Table A5.1 presents yield comparisons among sub-samples of AT and non-AT households taken from empirical research on the Mossi Plateau. Figures in parentheses are the percentage amount yields in AT households exceed those of non-AT households in Table A4.1. Yield effects are

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[1] Accompanying more timely operations can be an improvement in the quality of work being done -- i.e., better ridging during weeding activities.

Table A5.1: Donkey Tillage Technology

Study	Millet[1]	White Sorghum[1]	Red Sorghum[1]	Maize[1]	Peanuts[1]
SAFGRAD-FSU, 1983					
- Nedogo	354 (2)	444 (3.3)		836[2]	
- Diapangou		481 (32.5)		1181 (-7)[2]	
Jaeger, 1983					
- Nedogo	336 (-0.4)	343 (-33)	578 (37)	971 (-15)	435 (-13)
- Diapangou	403 (22)	256 (49)		1636 (14.5)	519 (103)
Singh, *et al.*, 1983	412 (17)	532 (25.8)		1324 (72)	440 (-9)
Swanson, 1982	305 (99)				167 (-47)
Kabore, *et al.*, 1983	314 (52)	461 (28)	1023 (96)		
Oxen Tillage Technology					
SAFGRAD-FSU, 1983					
- Diapangou		526 (44.9)			
Jaeger, 1983					
- Diapangou	391 (18.8)	368 (115)		1879 (31.5)	548 (114)

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[1] Figures in parentheses are the percentage change over respective manual technology yields.

[2] Donkey and oxen traction combined.

generally positive but show high variation. For example, yields of millet in non-AT households are from -0.4 to 99 percent larger than AT households. Comparable ranges for other crops are -33 to 115 percent for white sorghum, -15 to 72 percent for maize and -47 to 114 percent for groundnuts.

For purposes of the farm modelling work, Table A5.2 shows percentage increases (negative figures denote a yield decrease) in yields which accompany use of animal traction.

Table A5.2:

Type of Land	Crop	Percentage Yield Increases	
		Donkey	Oxen
Compound	Sorghums & millets	22	25
	Maize	30	32
Red Sorghum	Sorghums & millets	17	20
	Maize	22	25
	Cowpeas	-40	-40
White Sorghum	Sorghums & millets	12	15
	Maize	17	20
	Peanuts	-10	-10
	Cowpeas	-60	-60
Millet	Sorghums & millets	5	8
	Peanuts	-10	-10
	Cowpeas	-60	-60

The yield effects assumed in the analysis are generally less than actual performance (Table A5.1). Due to lack of information yield effects for oxen technology were assumed to be 3 percent greater than yield gains with donkey tillage.

Cowpea yields are assumed to fall 40-60 pe[illegible] with adoption of animal traction. Singh, et al. (1983) show that yields of cowpeas in association with millet decline from 21 to 5 kg/ha and cowpeas in association with white sorghum from 37 to 15 kg/ha with adoption of animal traction. The reasons for the decline are not clearly understood although inter-row weeding with animal traction likely deters the spread of plant growth. A negative yield effect is also assumed for peanuts, though the empirical research provides only weak support for this. The levels of yields assumed for hand, donkey, and oxen technologies utilized in the model are given in Table A4.2.[1]

Manure Effects

The acquisition of animals for traction purposes provides a source of manure that can be used to improve soil fertility. Manure production from one 400 kg ox has been estimated to vary from 7.5-10 tons/yr (Nourrissat, 1965).[2] Not all manure is recoverable. Assuming that 15% is recoverable and that 9 and 5 tons of manure are produced per year by an ox and donkey, respectively, then manure supply is 1.4 or .75 tons.[3]

These results compare favorably with Bonkian's (1980) research which show total manure use to be 1442 kg for animal traction (primarily donkey) households and 631 kg for hand tillage households.[4] The difference -- 811

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[1] Note yield levels may not exactly correspond to the respective percentages reported here due to adjustments made during the validation process.

[2] Cattle produce around 8.6 tons of solid manure per animal per year and 3.3 tons of liquid manure. Horses (donkey figures are not given) produce 5.9 tons of solid manure and 1.3 tons of liquid manure (Martin and Leanord, 1967, p. 139).

[3] This comes to 1.3 tons of recoverable ox manure. Delgado (1978) in his study assumed 1 ton of recoverable manure per animal though the Republique Francaise, Memento de l'Agronome (1975, p. 117) predicts 2.4 metric tons per year.

[4] Total manure includes manure from cattle, small ruminants, donkey, poultry, and households residues which were collected. These figures are probably underestimated (though equally so) because the study excluded several major sources of manure such as human "night soil" and night paddocking of animals.

kg -- should be the quantity of manure which is attributed to possessing donkey traction.

Manure is allocated to crops in varying proportions. Table A5.3 shows manure applications among crops and according to type of traction employed.

In general, maize receives the greatest quantity of manure application although adoption of donkey traction tends to increase the manure received by all crops, except for white sorghum.

Manure can be incorporated in the model in two ways: 1) improving the fertility of a given type of land; 2) expanding the area of a higher quality land type by creating, for example, red sorghum land out of white sorghum land. Bonkian's results suggest that the former approach is more realistic although this cannot be ascertained from the results shown. Area of various crops does expand, lending some credence to the second approach, although this is more likely to be due to the area expansion effects arising from animal traction's labor saving effects.

For modelling purposes, applications of manure are assumed to relax the constraints on availability of higher quality land types. This procedure avoids the problem of having to incorporate additional activities defining manure-yield production functions for the numerous crop enterprises incorporated in the model. Assuming that manure applications in Table A5.3 are grossly underestimated, it is assumed that the manure required to improve the quality of millet land to compound land is 16 tons, 9 tons for red sorghum land, and 5 tons per hectare for white sorghum land.[1] Given the definition of land types, (based on principal crops grown) one additional

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[1] Included here is an estimate of 10 tons of manure per year primarily on compound land that is attributed to household waste and night soil deposited by household members.

Table A5.3: Manure Application by Crop and Type of Traction (kg/ha)[a]

Crop	Hand	Donkey
Millet	319 (5)	1020 (4)
White Sorghum	1100 (1)	892 (5)
Red Sorghum	887 (8)	2704 (4)
Maize	5317 (10)	6867 (9)
Peanuts	700 (1)	3400 (1)

Source: Bonkian, 1980.

[a] Bonkian reports manure applications as a mean of all fields whether they received manure or not. The figures here have been adapted to show manure use on only those fields on which manure was applied. Figures in parentheses are number of fields receiving manure.

metric ton of manure can increase the area of compound land by .063 hectares (1/16 tons), red sorghum land by .111 hectares, and white sorghum land by .20 hectares from lower quality millet land.

Labor Saving Effects

Animal traction is primarily used to perform weeding operations on millet and sorghum but is rarely used in land preparation activities (ICRISAT, 1980).[1] Prior to rains the ground is too hard for plowing.[2] After the onset of rains, plowing is possible, but conflicts with planting activities. Planting of cereals can be done for only several days following

[1] Singh, et al. (1983) reports that none of the millet and sorghum fields, 38 percent of maize fields and 17 percent of peanut fields were worked with animal traction on land preparation activities in the village of Nedogo. By contrast, animal traction was used on 24 percent of millet fields, 46 percent of sorghum fields, 5 percent of peanut fields, and 0 percent of maize fields on weeding activities.

[2] A common soil preparation activity that is performed is line tracing (scarification of soil (3-5 cm) used to delineate rows. The operation facilitates line planting and subsequent weeding with animal traction equipment.

a major rain and this time is lost and risk of planting delayed if land plowing is performed.[1] Furthermore, sandy soils once plowed with light donkey equipment tend to collapse and cap with subsequent rains (ICRISAT, 1980).

Land preparation activities using animal traction are more commonly done on maize and peanut fields. Several factors contribute to this: 1) Planting of maize and peanuts normally take place at the time of first weeding of major cereals fields. Land preparation at this time seconds as a weeding operation and thus becomes a more productive activity; and 2) areas planted in maize and groundnuts tend to be small and the soil tends to be more easily cultivated due to the advance of the rainy season.

A summary of animal traction effects on human labor times, reported in various studies on the Central Mossi Plateau, are presented in Table A5.4. Information is provided on time worked by type of activity and by crop along with percentage change over hand tillage labor. Several observations are important. First, the number of studies which have evaluated the labor effects of adopting animal traction technology are not abundant. Second, information tends to be very scarce for such crops as red sorghum and/or by type of technology (no information is available for oxen traction). Third, results show wide variability and a high degree of inconsistency reflecting either high measurement error or poor control of other explanatory variables. Still, several conclusions might be drawn:

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[1] One would not expect this relationship to hold as the shift is made from an extensive to an intensive based agriculture. The expansion in total area farmed resulting from adoption of animal traction observed in Upper Volta (Jaeger, 1983) suggests that the orientation is towards extensification.

Table A5.4: Effects of Animal Traction on Human Labor Requirements

			Donkey Tillage Farms				
No.[1]	Study	Type of Activity	Maize	Red Sorghum	White Sorghum	Millet	Peanuts
2	Singh, et al, 1983	Land Prep.	178 (-18)		34 (26)	26 (8)	58 (-57)
		Planting	98 (11)		50 (-44)	50 (-26)	88 (6)
		First Weeding	244 (-6)		200 (-30)	176 (-26)	293 (-5)
		Second Weeding	234 (67)		124 (-34)	98 (-40)	
		Total	754 (7)		408 (-31)	350 (-29)	439 (-17)
3	Swanson, 1982 - Digie	Land Prep.					65 (-64)
		Planting				39 (11)	58 (-29)
		First Weeding				112 (-17)	164 (-9)
		Second Weeding				104 (11)	48
		Total				255 (-3)	357 (-20)
5	ICRISAT, 1980	First Weeding		695 (106)	384 (-31)	202 (-32)	
		Second Weeding		476 (78)	319 (-9)	136 (-19)	
		Total		___ (57)	___ (-25)	614 (-4)	
6	McIntire, July 1931[2]	Land Prep.	369 (111)	88 (319)	17 (183)	18 (-18)	159 (-42)
		First Weeding		695 (105)	384 (-31)	207 (-31)	303 (-14)
		Second Weeding		476 (78)	203 (-35)	148 (-11)	90 (-51)
		Total	956 (46)	1397 (93)	749 (-27)	457 (-19)	700 (-27)

1 These numbers correspond to the studies summarized in Table A3.2.

2 McIntire divides his animal traction sample into those using only animal traction for the task and those using mixed hand and animal traction techniques. Labor statistics by activity are sometimes reported in terms of both. In the case that they are, calculations are made to combine the sub-samples in order to obtain a "weighted average" labor time.

1) Donkey traction most benefits peanuts at land preparation time where labor savings of 42 to 64 percent are reported. Land preparation of sorghums and millet generally increase due to the practice of row tracing and absence of land preparation on such crops.
2) Donkey traction consistently decreases labor times at first weeding by 17 to 32 percent for white sorghum and millet. First weedings on peanuts also tend to decrease but to a lesser degree.
3) Donkey traction generally decreases human labor at second weeding of millet and white sorghum though results are highly variable.
4) Results for maize and red sorghum are highly variable and difficult to interpret. The results suggest that donkey traction increases labor times spent on red sorghum and to a lesser degree maize although it remains unclear why this should be so. One possible explanation is that such fields tend to be highly fertile. In light of the potential yield increases on such land, donkey traction may be used for intensification (plowing, better soil preparation, etc.) moreso than for extensification. Also, small field sizes tend to increase the efficiency of operations.

Based on the results presented in Table A5.4, the labor saving or labor augmenting effects associated with animal traction technology were estimated. These are given in Table A5.5.

Note that animal traction was assumed to increase labor on compound fields and also during period 1 (corresponding to land preparation and planting) for cereals to account for time spent on line tracing. For all other types of land and all other periods, animal traction was assumed to decrease human labor by the various percentages presented in the table. Information is nearly non-existent on the labor effects of oxen traction.

The labor effects assumed in Table A5.5 are derived synthetically from farmer attitudes data presented later in this section and extrapolations made from donkey tillage data in Table A5.4.

Labor Supply

A number of studies have shown that number of active workers per household increases with adoption of animal traction technology. Jaeger (1983) reports the number of active workers is 4.7 (hand tillage) and 6.6 (donkey) workers per household in the village of Nedogo and 4.4 (hand tillage), 6.4 (donkey) and 7.6 (oxen) workers per household for the village of Diapangou. Lassiter (1981) in the Michigan State eastern ORD study found that active workers per household increased from 3.5 workers for hand tillage households to 5.1 workers for animal traction households.[1]

The economic effect of an increase in the number of active workers per household is an increase in the potential labor stock that the household has available. It remains unclear why adoption of animal traction should be positively correlated with more workers but several possible explanations are: 1) animal traction permits the use of children (used to guide the traction team) who may not be otherwise effective workers at tillagae operations; 2) animal traction produces a wealth effect which attracts other kin to the household; and 3) larger family size, hence supply of labor, may be a prerequisite for AT adoption. In any case, incorporation of animal traction technology in the farm model should account for the labor stock effects.

It is assumed that adoption of animal traction permits an increase of the labor force of 1.5 workers for donkey traction adoptors and 2 workers

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[1] See also Kabore, Lebene, and Matlon (1983) and Whitney (1981).

Table A5.5: Labor Saving Assumed for Animal Traction Households[1]

Labor Period	Compound Land		Red Sorghum Land		White Sorghum Land			Millet Land	
	Sorghums and Millet	Maize	Sorghums and Millet	Maize	Sorghums and Millet	Maize	Peanuts	Sorghums and Millet	Groundnuts
	Donkey Tillage								
Period 1	30%	---	+ 16 hrs	---	+ 16 hrs	---	---	+ 16 hrs	---
Period 2	40%	---	-30%	---	-30%	---	-40%	-30%	-40%
Periods 3-5	40%	45%	-30%	-35%	-30%	-35%	-40%	-30%	-40%
Periods 6-7	25%	60%	-30%	-15%	-30%	-15%	-11%	-30%	-11%
Periods 8-10	25%	60%	-30%	-15%	-30%	-15%	-11%	-20%	-11%
	Oxen Tillage								
Period 1	30%	---	+ 13 hrs	---	+ 13 hrs	---	---	+ 13 hrs	---
Period 2	35%	---	-47%	---	-47%	---	-57%	-47%	-57%
Periods 3-5	35%	40%	-47%	-52%	-47%	-52%	-57%	-47%	-57%
Periods 6-7	22%	55%	-47%	-20%	-47%	-20%	-15%	-47%	-15%
Periods 8-10	22%	55%	-47%	-20%	-47%	-20%	-15%	-35%	-15%

[1] Figures are the percentage increase (a "-" implies a decrease) in human labor requirements using animal traction compared to labor requirements using hand tillage technologies in Table A3.2.

for oxen traction adoptors (Table A2.2). Further, it is assumed that the workers can work the same intensity per day as the animal traction teams they accompany -- 5.5 hrs/day for a donkey and 7 hrs/day for oxen (see the following section for these figures). Given the assumptions of days worked per week outlined in Table A3.5, the household's labor supply is augmented as follows:

Table A5.6: Additional Stock of Human Labor Due to Adoption of Animal Traction by Period Assumed in the Model

Constraint	Additional Stock of Man Hours Due to: Donkey Traction	Oxen Traction
1	116[a]	196[b]
2	50	84
•		
•		
•		
7	50	84
8	116	196
9	173	294
10	173	294

[a] For donkey households figures were derived as (116 man hours = 1.5 additional workers x 5.5 hrs/day x 14 days).

[b] For oxen households figures were derived as (196 man hours = 2.0 additional workers x 7.0 hours/day x 14 days).

These labor stocks are entered as columns in the LP tableau and increase RHS resource levels of labor if donkey or oxen tillage is utilized.

Determination of Number of Hours Worked by Donkeys and Oxen During Animal Traction Activity

Little information is reported in the literature concerning time spent by traction animals during cropping operations. Information is provided on the effect of animal traction on human time worked per hectare, but no flows of animal work are reported. The objective here is to derive a procedure for estimating hours of animal power required per hectare. Several checks are used to ensure that the assumptions bring about consistent results. The procedure is developed first for white and red sorghum and millet and later for maize and groundnuts. This distinction is made because animal traction is generally used to facilitate weeding with the former three crops, while it is commonly used to ease land preparation constraints with the latter two crops. The results are nearly the same, although the underlying set of assumptions differ.

Derivation of Animal Hours Worked on Sorghum and Millet Fields

Animal traction is used to facilitate weeding on major grain fields. Land preparation is not performed because plowing must wait until the arrival of the rains. After the rains, farmers place utmost importance in planting rather than plowing. The framework presented here is based on the use of animal traction for weeding activities.

Jaeger (1983) reports farmer's subjective estimates of time required to weed a field under various weeding technologies as:

By hand	- 10 days
Using donkey traction	- 5 days
Using ox traction	- 3 days

Time worked per day, however, depends on the type of technology employed. Jaeger notes in the same report that farmers' subjective responses for time an animal can work per day were 5 to 7 hours for a donkey and 6 to 8 hours for oxen. For purposes of this study it is assumed that:

- donkey can work 6.0 hrs/day on weeding
- ox can work 7 hrs/day on weeding
- man can work 5 hrs/day on weeding[1]

SAFGRAD-FSU (1983) reports that the number of hours spent on first weeding per hectare of sorghum at Nedogo was 240 hours. Labor times by FSU, however, are weighted to account for perceived age-sex productivity differences. Multiplying this figure by 1.2 (estimated weight to convert adjusted hours to unadjusted labor times) gives a figure of 288 hours. Singh, et al. (1983) reports 285 hours spent at first weeding of sorghum.

Given the above assumptions, the following computations can be made:

Hand Weeding Only

Jaeger does not provide information on the number of workers involved in field work, nor the size of field being cultivated. If 10 days are required to weed a field by hand and humans work an average 5.0 hours per day and 280 total hours are spent on weeding per hectare, then 5.6 workers must be involved in the weeding. This figure (i.e., 5.6) is near to the 6.0 workers assumed in this analysis and sets the norm for the following comparisons with animal traction performance.

Hand and Donkey Tillage Combined

Animal traction is generally accompanied by hand tillage to perform intra-row weeding and some spot weeding. Also, it is clear from the literature that the number of active workers increases with the adoption of animal traction (see labor supply section in Appendix 5).

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[1] See Appendix 3 for a review of labor intensity measures for agricultural workers. Five hours worked per day is a weighted average of male (2 males @ 6 hrs/day) and female (4 females @ 4.5 hrs/day) workers.

It is assumed the number of workers increases by 1.5 for donkey households (Appendix 2) and the additional workers work slightly longer hours per day to drive the team. The number of man-hours worked per hectare by households with animal traction then can be computed as:

(5.6 workers x 5 days x 5 hrs/day) +
(1.5 workers x 5 days x 6.0 hrs/day) = 185 hrs/hectare

Thus 5.6 workers performing manual weeding and 1.5 workers working with the donkey would work a total of 185 hours over 5 days. This represents a 34 percent reduction in human weeding time per hectare, consistent with labor savings observed at first weeding in the literature (see Table A5.1). The number of donkey hours worked in this model are:

1 donkey x 5 days x 5.5 hrs/day = 27.5 hours

Given the above information, a weight can be calculated to estimate the productivity (in terms of man-hours it replaces) of the donkey team:

185 man hours + (3.5) 27.5 donkey hours = 280 manual hours/hectare

This weight says that given current agronomic practices followed by Burkinabe farmers, one donkey hour substitutes for 3.5 human hours at weeding. This figure is important because it permits solving for donkey hours worked per hectare from other socio-economic information observed. Two types of information are given in the literature: 1) Total hours and hours worked by activity by hand or primarily hand-tillage households; and 2) Total hours and hours worked by activity with animal traction or by animal traction households. Thus, given the above assumptions we can derive animal hours worked per hectare by:

$$\text{Donkey Hours Worked} = \frac{\text{Hours Worked (manual HHDs)} - \text{Hours Worked (with AT)}}{3.5}$$

This is a crude approximating procedure but consistent with information available in the literature.

Hand and Oxen Tillage Combined

With oxen traction, the number of active workers per household is generally higher than either donkey households or hand tillage households. Jaeger (1983) shows active workers to increase from 4.4 for hand tillage HHDs to 6.4 for donkey HHDs to 7.6 for oxen HHDs. Following the same procedure employed above for donkey tillage, the number of man-hours worked using oxen traction technology (assuming 2.0 additional workers relative to hand tillage households) can be estimated as:

(5.6 workers x 3 days x 5 hrs/day) +
(2.0 workers x 3 days x 7 hrs/day) = 126 hrs

Time worked per hectare of 147 hours would represent a 55 percent decrease in human hours required per hectare. No information was located which could validate this figure.[1] An ox under this scenario would work:

1 ox x 3 days x 7 hrs/day = 21 hours

Given the assumptions of this model then, the productivity weight of an oxen unit can be calculated as:

$$\frac{126}{\text{man-hours}} + \frac{(7.3)\ 21}{\text{ox hours}} = \frac{280 \text{ hand tillage hours}}{\text{worked on WS per hectare}}$$

The weight of 7.3 says 1 hour of oxen time replaces roughly 7 hours of human labor time. Hence, work with an oxen unit is roughly twice as efficient as is work with a donkey.

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[1] While information is available for the effects of donkey traction it is nearly non-existant for oxen traction technology.

The number of oxen hours worked per hectare then can be calculated as:

$$\text{Ox hours worked} = \frac{\text{Hours Worked (manual HHDs)} - \text{Hours Worked with AT}}{7.3}$$

Derivation of Time Worked by Donkeys and Oxen in Cultivation of Peanuts and Maize

From Singh, *et al*. (1983) the amount of time spent preparing peanut land by hand for planting was around 140 hrs/hectare. Normally land is planted in very small plots (less than 0.5 ha is planted in total). Assume that 2.0 persons would normally be involved in hand hoeing (plowing) a field.

The amount of time an animal can work per day of plowing is reported by Jaeger (1983) from farmers' subjective responses in the village of Nedogo: Donkeys reportedly could plow 4-6 hours/day and oxen 7-8 hours per day. Given that plowing tends to be a more strenuous activity than weeding, these hours tend to overstate the work times reported earlier. Assume then that

- a donkey can plow 5 hours/day
- an oxen can plow 6 hours/day
- a man can plow 4 hours/day.

Jaeger reports as well that plowing a field (size unknown) with donkey traction requires 8 days while with oxen 5 days (no base is provided for hand plowing in Jaeger's study). Given the above assumptions, 2 persons plowing the field by hand would require 17.5 days to plow a 1 hectare field entirely. That is,

2.0 workers x 17.5 days x 4 hrs/day = 140 hrs/hectare

With donkey traction, work times would be reduced as follows:

(2.0 workers x 4 days x 4 hrs/day) +
(1.5 workers x 4 days x 5 hrs/day) = 62 hrs

Donkey traction reduces human labor times by 56 percent, consistent with the reduction in labor times observed for peanuts in Table A5.4. The productivity factor for donkeys can then be calculated as:

62 worker hours + (3.9) 20 donkey hours = 140 hrs/hectare

Given man hours worked without animal traction and man hours worked with animal traction, the number of hours worked by the donkey team per hectare of peanuts can be computed as:

$$\text{donkey hours worked} = \frac{\text{manual hours under hand-tillage practices} - \text{manual hours using donkey traction}}{3.9}$$

Similarly for oxen, given Jaeger's ratio of field completion time by oxen/donkey 5/8, a field could be plowed in 2.5 days. The number of hours worked per hectare can be calculated as:

(2.0 workers x 2.5 days x 4 hrs/day) +
(2.0 workers x 2.5 days x 6 hrs/day) = 50 hrs/hectare

representing a 64 percent reduction in human labor. The productivity factor for oxen can then be computed as:

50 hrs + (6) 15 hrs = 140

Thus oxen hours can be derived from observations of human labor worked by:

$$\text{oxen hours worked} = \frac{\text{man hours worked without animal traction} - \text{man hours worked with animal traction}}{6}$$

APPENDIX 6

TIED RIDGING TECHNOLOGY

One of the promising new technologies to come forth from agricultural research efforts in Burkina Faso is tied ridging technology. Tied ridging consists of forming small "dams" between crop rows at distances of every meter or so in the field (in some cases longer) to facilitate entrappement of rainfall and encourage water infiltration. When combined with improvements of soil fertility and use of animal power -- to reduce the labor requirements associated with constructing ridges -- dramatic yield increases are possible.

The important economic question, however, is whether sufficient economic incentives exist for farmers to adopt the new tied ridging technology. Higher yields from an agronomic perspective are necessary for adoption but not sufficient from an economic point of view. The base model developed for the traditional farm enterprise in this study is expanded to evaluate the new technological option. This is done by adding new activities (columns) to the linear programming model. Each activity represents a specific technology possessing its own unique set of demands for resources -- human and donkey labor by period, land, and fertilizer. Two new rows are added to the model corresponding to resource constraints for urea and compound fertilizer. The new technologies will enter the model solution only if profits from using tied-ridging and fertilizer are greater than the returns achieved under existing management practices.

The practice of tied-ridging involves two separate operations. First, there is construction of ridges within the row. Then there is the subsequent operation of "tieing" the ridges together by forming ridges across rows. The manner in which these operations are performed can vary considerably. It's possible, for instance, that the operation of ridging (cum weeding) be done entirely by hand but this results in considerable demands for human labor and, in view of labor bottlenecks that exist, may result in poor ridging operations being performed. Animal traction however can reduce the human labor requirements for preparation of ridges. Also, it may facilitate better ridge construction; with donkey traction, for instance, ridges 5" high may be formed, while with the stronger oxen, technology ridges as high as 8" may be constructed. Land preparation accompanying tied ridging can also lead to better water retention by the soil.

For purposes of this study, donkey traction technology is used to evaluate the tied-ridging technology. While oxen would perhaps be more efficient at doing the ridging work, donkey traction is more common on the Mossi Plateau. Moreover, animal traction cum tied ridging research has been done primarily with donkey traction. It remains both an empirical and economic question to what extent hand tillage or oxen traction technologies represent economically viable alternatives.

White sorghum is used in the model to evaluate the impact of the new technology. This crop was selected for several reasons. First, tied-ridging research is relatively abundant for white sorghum compared to the sketchy data available for other crops. Second, improved yields for white sorghum would likely have greater impact on total food production than improvements in maize, whose area cultivated is much smaller and constrained by risk considerations. Millet was not chosen since it demonstrated a low yield response to the new technology in on-farm research. Third, sufficient information exists for white sorghum to make an adequate appraisal.

To incorporate the new technology into the model the following technical information is required:

- Tied Ridging Operation: A clear definition of the tied ridging technology. That is, information is required on the time of agricultural season that ridging, "tieing" of ridges and fertilizer applications are performed, whether animal traction is involved in construction of the ridges and information on type and quality of tied ridging work that is done.
- Labor: The amount of additional human labor time it takes to construct the tied-ridges and apply fertilizer. Also, the time of the agricultural season when labor operations are performed.
- Fertilizer: the types and quantities of inorganic fertilizers which are used. Also, information on the yield response of white sorghum to applications of fertilizer and tied ridging.

Table A6.1 summarizes the results of various tied ridging experiments performed in Burkina Faso. Information is presented on yield differences associated with various combinations of tillage practice, fertilizer applications and type of traction systems used. The experiments fall under two general categories: 1) Farmer managed trials are those where all field work and management are done by the farmer with minnimum direction by researchers. 2) Research Managed Trials are conducted by the researcher and probably receive better management -- i.e., tied ridges and fertilizer applications are done in a more timely manner and better construction of tied ridges takes place. This is reflected in the higher yield response levels generally observed for the researcher managed trials.

The technology of tied ridges plus applications of fertilizer all use applications of 100 kg/ha of cotton fertilizer (14-25-15 NPK) and 50 kg/ha urea. With the exception of trial #27, ridges were formed while performing first weeding with donkey traction, and were tied just before second weeding (roughly 35-45 days following planting).

Table A6.1: White Sorghum: Summary Table of Changes in Yields From Alternative Technologies

	Trial Number	Location[a]	Traction[b]	Traditional	Post-Technology Increase	Post-Technology Total	Remarks[c]	Source
I. Tied Ridges Technology								
A. Farmer Managed Trials	1	B	M	406	+87	493	TR-A	1, Table 3
	2	N	M	430	+54	484	TR-A	1, Table 3
	3	D	M	363	+78	441	TR-A	1, Table 3
	4	N	D	444	+180	624	TR-A	
	5	D	D	481	+71	552	TR-A	1, Table 3
	6	D	O	526	+52	578	TR-A	1, Table 3
	7	K	D/O	581	+104	685	TR-A	4, P. 165
B. Research Managed Trials	8	N,B,D_1,D_2,Y_1,Y_2	---	385	+195	580	TR-B	2, P. 63
	9	"	---	385	+176	561	TR-A	2, P. 63
II. Fertilizer Technology								
A. Farmer Managed Trials	10	B	M	406	+299	705	F1	1, Table 3
	11	N	M	430	+117	547	F1	1, Table 3
	12	D	M	363	+356	719	F1	1, Table 3
	13	N	D	444	+160	604	F1	1, Table 3
	14	D	D	481	+356	837	F1	1, Table 3
	15	D	O	526	+331	857	F1	1, Table 3
	16	K	D/O	581	+357	938	F1	4, P. 165
B. Researcher Managed Trials	17	N,B,D_1,D_2,Y_1,Y_2	---	385	+374	759	F1	2, P. 63
	18	Kam	---	1080	+500	1580	F2	3, P. F11
	19	Kam	---	1080	+1000	2080	F3	3, P. F11

Table A6.1: (continued)

		Trial Number	Location[a]	Traction[b]	Traditional	Post-Technology Increase	Post-Technology Total	Remarks[c]	Source
III. Tied-Ridges and Fertilizer Technology									
A.	Farmer Managed Trials	20	B	M	406	+284	690	TR-A	1, Table 3
		21	N	M	430	+421	851	TR-A	1, Table 3
		22	D	M	363	+390	753	TR-A	1, Table 3
		23	N	D	444	+518	962	TR-A	1, Table 3
		24	D	D	481	+390	871	TR-A	1, Table 3
		25	D	O	526	+465	991	TR-A	1, Table 3
		26	K	D/O	581	+583	1164	TR-A	4, P. 165
B.	Research Managed Trials	27	N,B,D_1,D_2,Y_1,Y_2	---	385	+563	948	TR-B	2, P. 63
		28	"	---	385	+745	1130	TR-A	2, P. 63

Sources: 1/ SAFGRAD-FSU, 1984. Farming Systems Research in Upper Volta, 1983 Annual Report, Ouagadougou, Upper Volta.

2/ SAFGRAD-FSU, 1983. Farming Systems Research in Upper Volta, 1982 Annual Report. Ouagadougou, Upper Volta.

3/ International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 1982. Annual Report, 1981, Ouagadougou, Upper Volta.

4/ Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (I.R.A.T.), 1983. Rapport de Synthese, 1982, Ouagadougou, Upper Volta.

Table A6.1: (continued)

Notes and Remarks:

a/ Location Names: B = Bangasse; N = Nedogo; D = Diapangou; K = Koudougou; Kam = Kamboinse; Y = Yako.
b/ Traction: M = Manual; D = Donkey; O = Oxen.
c/ TR-A: The tieing of the tied-ridges took place after planting (at second weeding)
TR-B: The tieing of the tied-ridges took place before planting.
F1: 100 kg/ha (14-25-15 NPK) cotton fertilizer + 50 kg/ha urea.
F2: 100 kg/ha (14-25-15 NPK) cotton fertilizer + 33 kg/ha urea.
F3: 100 kg/ha (14-25-15 NPK) cotton fertilizer + 66 kg/ha urea + 450 kg/ha rock phosphate.

Dramatic yield increases are observed when tied ridging and fertilizer are combined. Yield increases range from 390-583 kg/ha for tied-ridging trials using donkey traction on farmer managed fields. On research managed trials, yield increases of 563-745 kg/ha are reported. Considering that yields under traditional technology vary around 385-581 kg/hectare, these yield responses represent a doubling in yields.

The results of Table A6.1 are synthesized to obtain a representative technology with the following characteristics:

- Type of Land: The new white sorghum technology is assumed to compete for traditional white sorghum technologies on white sorghum land. This distinction is important since the type of land on which the technology is tested impacts on the outcome of the experiment.[1]
- Schedule of Activities: Ridging operations are assumed to be done at time of first weeding with donkey traction technology. Since this operation is already done in the base model, no additional time is required. Tieing of ridges is done using only hand labor and takes place at the end of first weeding on major cereals when labor demands are less constraining. Fertilizer is applied after planting but prior to the peak labor demands of first weeding.
- Labor: To define the labor profile of the new technology, the additional time required for fertilizing and tied-ridging are added in appropriate periods to the labor profiles of white sorghum on white sorghum land. Data on the number of human hours to construct tied-ridges is sketchy. Two estimates exist. SAFGRAD/FSU uses a figure

[1] The new white sorghum technology could be tested on compound land, for instance, but the scarcity of information on labor times and yield response make the evaluation difficult.

of 50-100 hours per hectare to tie ridges together[1] while IRAT reports a figure of 160 hours per hectare. This difference probably reflects either different operations or different quality of work performed. For purposes of this model it's assumed that an additional 100 hours of labor are required at the end of first weeding which corresponds to the 7th labor period. Subsequent analyses are then done to assess the sensitivity of model solutions to labor inputs of 75, 125, and 150 hours/hectare. An additional labor input of 5 hours/hectare for applying fertilizer is assumed to take place in labor period 4, prior to the critical first weeding labor bottleneck.

- Fertilizer: The white sorghum receives treatment of 50 kg/ha of cotton fertilizer following the planting period. Two price scenarios are assumed. A price of 62 CFA/kg for cotton fertilizer and 60 CFA/kg for urea are used as financial prices in the model. However, fertilizer in Burkina Faso is subsidized at a rate of approximately 40 percent (World Bank, 1981). For purposes of economic analysis, fertilizer prices of 103 CFA/kg for cotton fertilizer and 100 CFA/kg for urea are assumed to evaluate the new technology at unsubsidized rates.

- Yields: The yield of white sorghum under donkey traction technology on white sorghum land is 493 kg/ha (Appendix 4) in the "base" farm model. Assuming that a yield response of 350 kg/ha were possible (this is on the lower end of yield effects actually observed), the

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1 The operation essentially requires an individual to walk down a row and construct a tied-ridge at distances of every meter or so.

yield of the new technology would amount to 850 kg/ha. However, for purposes of sensitivity analysis, a yield figure of 950 kg/ha, representative of an optimistic scenario, and figures of 650 and 750 kg/ha, representative of pessimistic scenarios, are also tested. Compared with base yields of 493 kg/ha, yields of 650, 750, 850, and 950 kg/ha would result in yield responses of 157, 257, 357, 457 kg/ha. These figures tend toward the conservative side, but cover the range of yield responses observed in farmer managed trials.

APPENDIX 7

MODEL SOLUTIONS

Table A7.1: Model Solutions Incorporating the New Tied Ridging Technology Under Various Yield, Labor, and Price Assumptions.

Yield (kg/ha) Price of Fertilizer (Urea/Compound) Hours (add in period 7)	Donkey Tillage Only	650 60/62 75	650 60/62 100	650 60/62 125	650 60/62 150	650 60/62 175	750 60/62 75	750 60/62 100	750 60/62 125	750 60/62 150	750 60/62 175
Total Net Revenue Per Household (FCFA)		182,519	182,455	182,416	182,391	182,373	184,865	184,172	183,792	183,538	183,357
CL-Maize-Hand (ha.)	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
RS-RS/CP-Donkey (ha.)	.09	.08	.08	.08	.08	.08	.11	.08	.08	.08	.08
RS-Maize-Donkey (ha.)	.55	.55	.55	.55	.55	.55	.52	.55	.55	.55	.55
WS-WS/CP-Donkey (ha.)	.80	.41	.51	.57	.61	.63		.51	.57	.61	.63
WS-WS-New Tech (ha.)	--	.39	.29	.23	.19	.17	.80	.29	.23	.19	.17
ML-ML/CP-Hand (ha.)	.82	.82	.82	.82	.82	.82	.03	.82	.82	.82	.82
ML-ML/CP-Donkey (ha.)	3.91	3.92	3.92	3.92	3.92	3.92	.97	3.92	3.92	3.92	3.92
ML-ML-Donkey (ha.)	--	--	--				3.67				
ML-PN-Hand (ha.)	.17	.18	.17	.17	.17	.17	.42	.17	.17	.17	.17
ML-PN-Donkey (ha.)	.07	.08	.08	.08	.07	.07	.05	.08	.08	.07	.07
Opportunity Costs: (FCFA/hr.)											
Labor Hours - Period 1		82.6	82.7	82.7	82.7	82.7	78.8	81.4	81.7	81.9	82.0
Period 5		347.2	347.3	347.3	347.4	347.4	345.8	345.8	346.2	346.4	346.5
Period 6		67.4	69.4	70.6	71.4	72.0	0	15.8	27.6	35.6	41.2
Period 7		8.8	6.6	5.3	4.4	3.88	85.4	65.2	52.2	43.5	37.3

Table A7.1: (continued)

Yield (kg/ha) Price of Fertilizer (Urea/Compound) Hours (add in period 7)	850 60/62 75	850 60/62 100	850 60/62 125	850 60/62 150	850 60/62 175	950 60/62 75	950 60/62 100	950 60/62 125	950 60/62 150	950 60/62 175
Total Net Revenue Per Household (FCFA)	189,585	187,261	185,669	184,687	184,340	194,623	191,198	188,706	187,138	186,017
CL-Maize-Hand (ha.)	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
RS-RS/CP-Donkey (ha.)	.11	.11	.11	.10	.08	.06	.50	.11	.11	.11
RS-Maize-Donkey (ha.)	.53	.53	.53	.54	.55	.54	.13	.53	.53	.53
WS-WS/CP-Donkey (ha.)	--	.16	.29	.55	.63	--	--	.29	.37	.43
WS-WS-New Tech (ha.)	.80	.64	.51	.25	.17	.86	.80	.51	.43	
ML-ML/CP-Hand (ha.)	.03	--	--	.50	.82	--	--	--	--	
ML-ML/CP-Donkey (ha.)	.97	--	--	--	3.92	--	--	--	--	
ML-ML-Donkey (ha.)	3.67	4.69	4.69	4.16		4.69	4.00	4.69	4.69	4.69
ML-PN-Hand (ha.)	.42	.43	.43	.26	.17	.43	.49	.43	.43	.43
ML-PN-Donkey (ha.)	.05	.07	.06	.02	.07	.06	.35	.06	.06	.05
Opportunity Costs: (FCFA/hr.)										
Labor Hours - Period 1	78.0	66.5	75.0	80.8	81.3	52.4	49.5	58.8	67.2	73.2
Period 5	345.8	345.8	344.5	345.5	345.7	346.2	346.3	346.1	345.8	345.7
Period 6	0	0	0	0	10.5	0	0	0	0	0
Period 7	84.5	123.7	99.1	82.7	70.9	164.6	173.0	146.0	121.8	104.5

Table A7.2: Model Solutions Incorporating the New Tied Ridging Technology Under Alternative Labor Scenarios, Evaluated at the Unsubsidized Price of Fertilizer.

Yield (kg/ha) Fertilizer Price (Urea/Compound) Additional Labor Hours	Donkey Tillage Only	850 100/103 75	850 100/103 100	850 100/103 125	850 100/103 150	850 100/103 175
Total Net Revenue		184,737	184,113	183,745	183,499	183,323
CL - Maize - Hand (ha.)	.16	.16	.16	.16	.16	.16
RS - RS/CP - Donkey (ha.)	.09	.09	.08	.08	.08	.08
RS - Maize - Donkey (ha.)	.55	.54	.55	.55	.55	.55
WS - WS/CP - Donkey (ha.)	.80	.31	.51	.57	.61	.63
WS - WS - New Tech (ha.)	--	.49	.29	.23	.19	.17
ML - ML/CP - Hand (ha.)	.82	.50	.82	.82	.82	.82
ML - ML/CP - Donkey (ha.)	3.91	4.17	3.92	3.92	3.92	3.92
ML - ML - Donkey (ha.)	--	--	--	--	--	--
ML - PN - Hand (ha.)	.17	.26	.17	.17	.17	.17
ML - PN - Donkey (ha.)	.07	.03	.08	.08	.07	.07
Labor Hours - Period 1		79.8	81.4	81.7	81.9	82.0
(FCFA/hr.) Period 5		345.6	345.9	346.2	346.4	346.6
Period 6			17.6	29.1	36.8	42.3
Period 7		84.0	63.2	50.5	42.2	36.2